ANNUAL REPORT

of the

SHIP STRUCTURE COMMITTEE

May 1, 1961

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Convened by

THE SECRETARY OF THE TREASURY

SHIP STRUCTURE COMMITTEE

MEMBER AGENCIES:

BUREAU OF SHIPS, DEPT. OF NAVY
MILITARY SEA TRANSPORTATION SERVICE, DEPT. OF NAVY
UNITED STATES COAST GUARD, TREASURY DEPT.
MARITIME ADMINISTRATION, DEPT. OF COMMERCE
AMERICAN BUREAU OF SHIPPING

ADDRESS CORRESPONDENCE TO:

SECRETARY
SHIP STRUCTURE COMMITTEE
U. S. COAST GUARD HEADQUARTERS
WASHINGTON 25, D. C.

June 20, 1961

Dear Sir:

Herewith is a copy of the Annual Report of the Ship Structure Committee to the convening authority, the Secretary of the Treasury, covering the activities of the Committee and its affiliated research groups for the year ending May 1, 1961. Technical portions of this report are a continuation of the series of technical progress reports that began with the publication in 1946 of the Final Report of the Ship Structure Committee's predecessor, the Board to Investigate the Design and Methods of Construction of Welded Steel Merchant Vessels.

Any questions, comments, criticisms, or other matters pertaining to the report should be addressed to the Secretary, Ship Structure Committee.

This report is being distributed to those individuals and agencies associated with and interested in the work of the Ship Structure Committee.

Sincerely yours,

E. H. Thiele
Rear Admiral, U. S. Coast Guard
Chairman, Ship Structure
Committee

CONTENTS

TECHNICAL SUMMARY

Fundamental Design: An automatic system for recording midship bending strain has been installed on a C-4-S-B5 dry cargo ship operating in the North Atlantic. Detailed magnetic-tape records have been made of dynamic strains resulting from long-period waves and from slamming. These first records are of a quality suitable for statistical analysis by high-speed computer methods.

Tests have been conducted under extreme wave conditions on a Mariner dry-cargo ship model with two different loading conditions: (1) as designed, with a radius of gyration of 24 per cent of the ship length, and (2) with the cargo concentrated amidships, resulting in a radius of gyration of 16 per cent of the length. These tests have demonstrated that it is possible to achieve a wave bending moment greater than is obtained from the static calculation for a L/20 wave. Although the reduction in radius of gyration makes the model more seakindly, the bending moment can be as much as 75 per cent greater than in the model loaded in the as-designed condition.

Fabrication and Flaw Detection: In a study of methods for measuring residual stress patterns, stress-corrosion-cracking tests were conducted on welded specimens of mild steel and of several grades of high-strength steel. The tests on commercial high-strength, heat-treated structural steel produced patterns similar to those previously obtained from hydrogen cracking in SAE 4340 steel. Systematic patterns from stress-corrosion-cracking did not occur in the other steels tested. In tests of hydrogen-induced cracking of SAE 4340 steel containing residual stresses, the occurrence of cracking was found to be dependent on the stress rather than the associated inelastic strain.

In tests directed toward the development of instruments for the non-graphic inspection of welds, it has been found that the maximum sensitivity for detection of flaws deep in a plate results when the back-scattered gamma photons and the incident gamma photons are nearly perpendicular to the test specimen. Under this project, the investigators have designed and constructed an instrumentation system that should overcome in part the deterioration of sensitivity that is associated with increasing specimen thickness, through a means

for increasing the detector area with increasing depth.

Commercial application of ultrasonic inspection has occurred as a result of interest generated in part by the SSC program. Upon the completion of ultrasonic inspection of 12 stern-frame and rudder castings greater than 9 in. thick, the investigator concluded that ultrasonic inspection is "extremely suitable" for this purpose, as no large objectionable defects were found during subsequent machining of these castings. As an assist to visual and X-ray weld inspection, ultrasonics has been used during a 12-month period at one shipyard. Marked improvement in weld quality has occurred, and an increased percentage of the radiographs contain flaws because only those areas found defective by ultrasonics were radiographed. The capability of ultrasonic scanning to cover a much greater length of weld than radiography in a given period has been found to be of great value to both the shipyard and the inspector.

Fracture: In a study of the influence of manganese on structural behavior, rimmed steel containing 0.36 per cent manganese exhibited cleavage microcracks following fracture while a semikilled steel with 1.30 per cent manganese contained no microcracks following fracture. It is concluded that crack propagation is limiting in the low-manganese steel while crack initiation is limiting in the high-manganese steel. Manganese does not appear to influence twinning.

In related tests, the grain-size and temperature dependence of the lower yield stress was found to conflict with the theory of dislocation locking by interstitial atoms. A stress- and temperature-dependence of dislocation velocities was developed that can satisfactorily explain this discrepancy.

It has been found in an examination of substructure in steel that a reduction in subgrain size increases the transition temperature, in contrast to the effect of grain size. It is suggested that this effect may have some connection with the stress-relief annealing of welds. Examination of fracture surfaces of iron single- and bi-crystals indicates that the origin of cleavage appears always to be at a barrier such as a twin or a grain boundary.

In tests on mild steel at high strain rates, departures from an equation-of-state relationship for the stress-strain curve can be correlated with the

density of slip lines associated with the different straining rates. Irregularities of behavior of the lower yield stress during dynamic testing result from the failure of a steady state strain level to be reached in regions traversed by the Lüders band front. The general trends of behavior under high strain-rate conditions are found to be in agreement with the effects of composition on Charpy transition temperatures.

An investigation of tensile and compressive prestrain of mild steel and its effect on fracture behavior has revealed a marked sensitivity of fracture to prestrain temperature. For example, only 35 per cent compressive prestrain by bending at 400 F is needed to embrittle a rimmed steel when it is unbent at 75 F, whereas 57 per cent compressive prestrain at 75 F is needed to embrittle the same steel tested at 75 F. In other tests in which a bar of A-7 steel is bent at 450 F to a tensile strain in its outer fiber of 35 per cent, fracture occurs at a test temperature of -16 F after an additional tensile strain in the outer fiber of only 2 per cent.

Tests were conducted in which a steel bar is bent and then unbent, but the maximum inelastic strain is kept smaller than the strain required to embrittle the material. For a small number of bend-unbend cycles, no cumulative damage effects could be detected.

Tests to measure the relative influence of residual stresses on embrittlement have supported earlier work. Specimens containing residual stresses but without inelastic prestrain failed in a ductile manner, while specimens that were prestrained but did not contain residual stresses failed with a marked reduction in ductility. When notched specimens that were initially prestrained and thus contained residual stresses were treated so as to remove the residual stresses without eliminating the damaging effects of the prestrain, a reduction in ductility resulted.

Comparative tests were made on 6-ft wide steel plates containing central regions in compression, tested at -10 F with an average applied stress of 3000 psi. Under identical notch-wedge impact methods of starting a running crack, the plate that contained a residual compressive strain of 300 micro in. per in. produced a crack that stopped after running 54 in., while the plate that con-

tained a residual compressive strain of 100 micro in. per in. fractured completely. The minimum measured crack velocity in the first plate was 150 ft per sec, while for the second plate the minimum velocity was 350 ft per sec; maximum measured crack velocities were of the same order of magnitude for both plates, 6000 ft per sec. It was observed in these and other wide-plate tests that the crack usually ran in a direction perpendicular to the maximum principal stress and that the strain field very near to the tip of the crack approached biaxiality.

In a test of a 6-ft-wide plate without a residual stress field, the magnitude of the local strain between 1/2 and 1 in. from the crack tip was measured as 2000 to 4000 micro in. per in. In the wide plates with residual compressive strain in the central regions, the strain measured 1/2 to 1 in. from the tip of the crack when the crack was in the residual compressive strain region ranged from 500 to 1000 micro in. per in.

Tests were conducted with Wells-type specimens, which contain a longitudinal butt weld that joins two halves of a previously notched plate. At -40 F, two 3/4-in. thick plates failed at 9400 and 9900 psi, while at the same temperature two other plates 5/8-in. thick failed at 18,000 and 40,000 psi.

A study of low-cycle fatigue of mild steel has demonstrated that the direction of the first loading, that is, tension or compression, may have a very marked effect on the behavior in the low-cycle range, but that this effect diminishes with increasing fatigue life. In tests of flat plates containing sharp central notches, reduction in test temperature reduces the rate of fatigue crack propagation but may produce a brittle fracture. It was found that strain aging has little or no effect on the low-cycle fatigue behavior of ABS Class-C normalized steel.

One welded plate specimen of rimmed steel containing a central notch failed in a brittle manner from a fatigue crack 1/8 in. long produced by $\pm$25,000 psi for 13,700 cycles; thus it may be concluded that either residual stresses or changes in properties associated with welding can have a significant influence on fracture behavior.

Tests were made on controlled rolled steels covering a range of severity from 15 per cent reduction at 1950 F to 60 per cent reduction at 1250 F. These

steels were found to cover a range of grain size of only two ASTM units. Tensile tests in the rolling, transverse, and thickness directions revealed marked changes in behavior in the temperature range between room temperature and 50 K. The fracturing anisotropy between the extremes of rolling and thickness directions (with transverse properties intermediate) is not strongly dependent upon rolling history. Ductility transitions occur in unnotched tensile tests at about 70--80 K for cylindrical specimens machined and tested in the rolling direction, and at about 80--90 K for most of the thickness-direction specimens. For the steel rolled at 1250 F, however, the ductility transitions in the thickness direction ranged to an upper limit of 170 K for the 60 per cent reduction. Another unusual feature of this same plate and of the plate reduced 30 per cent at 1250 F was the occurrence of fracture at below-yield stresses in the thickness-direction specimens at temperatures more than 30 K below the ductility transition; the range of stresses for fracture extended to as low as 1/2 the yield stress. In rolling-direction specimens of these same plates in the same temperature range, fracture sometimes occurred away from the neck or splitting sometimes occurred, but the stress was always equal to or greater than the yield stress.

Steel Quality: Tests have been completed on ABS Class-B and C steels obtained directly from five mills. No marked variations were found in the tensile properties. Extremes of segregation were found only in the B steel, where 95 per cent of the top and center plates exhibited segregation, while only 29 per cent of the bottom plates did, and these latter cases exhibited only faint segregation. In the Class-C steel, 65 per cent of the top and the center plates exhibited segregation, while only 6 per cent of the bottom plates showed segregation and then only extremely faintly. No consistent correlation was obtained between notch toughness and specimen location in a plate. The principal variations appear to arise from differences between heats.

Tests of Class-C steel indicate no particular significance to ingot location or plate position, while for Class-B steel, significant variations were observed between heats and between plates, but the effect of ingot location could not be determined.

The mean Charpy V 15 ft-lb transition temperature of 39 plates of Class-B steel was 7.5 F, with a standard deviation of 12.8 F. The corresponding values for Class-C steel are -14.3 F and 10.0 F.

Tests on normalized plates from three experimental commercial heats of semikilled, hot-rolled plate steel of 3/4, 1 1/4, and 1 1/2 in. thickness, containing 0.20 per cent maximum carbon and 1.00--1.35 per cent manganese, indicate an average reduction of 13 F in Charpy V 15 ft-lb transition temperature as a result of normalizing, and this enables the Charpy V 15 transition temperature of 1 1/2 in. thick plate of this material to fall below 10 F. The average improvement (reduction) in the van der Veen fracture appearance transition temperature from normalizing was 29 F, and in the drop-weight nil-ductility transition temperature, 39 F. It is concluded that normalized plates of this steel in thicknesses to 1 1/2 in. would have about the same notch toughness characteristics as hot-rolled ABS Class-C steel

In a project studying the influence of manganese on Charpy V 15 and nil-ductility transition tests, a wide range of laboratory heats of semikilled and killed steels was tested. The conclusions include the following: An increase of 0.1 per cent carbon increases nil-ductility transition 19 F and Charpy V 15 16 F; an increase of 0.1 per cent manganese decreases nil-ductility transition 2 F and Charpy V 15 7 F. It was observed that a reasonably good correlation exists for these materials among nil-ductility transition, 0.015-in. lateral expansion in the Charpy test, and 15 per cent shear and 15 ft-lb in the Charpy test.

A study of the needs for optimum composition of steels over 1 1/2 in. in thickness has concluded that even on the basis of the metallurgical effect of thickness alone, it would not be advisable to utilize ABS Class-C steel in thicknesses greater than 1 3/8 in. without normalizing. It is also concluded that geometric effects of thickness continue to at least 4 in. in thickness. The study recommends a careful examination of the geometric effect of notch tough

ship steel, such as normalized ABS Class-C, normalized ABS Class-C that is modified by containing 0.85--1.15 per cent manganese, and ABS Class-C modified that is quenched from 1650 F and tempered at 1150 F; laboratory tests on this latter steel indicate that it has a Charpy V 15 of -125 F.

RESEARCH PROGRAM OBJECTIVES

The Ship Structure Committee Program is divided into three parts: Materials Research, Design Research, and Fabrication Research. The following summaries of objectives are presented to provide an understanding of the short- and long-range goals of Ship Structure Committee research and of how current and anticipated projects fit into the overall program.

The Materials Research Program

The purpose of the Ship Structure Committee is to sponsor research directed toward improvement of the hull structures of ships; thus, the portion of that program advised by the Committee on Ship Steel must discover and develop these improvements in ship steel that can result in improved hull structures. Reductions in weight and increases in strength, toughness, and weldability can, therefore, qualify as such improvements if they are economically feasible. The objectives of the Materials Research Program can be achieved through sponsorship of research that is balanced between a) fundamental studies that promise to increase our understanding of the mechanisms of fracture of metals, b) applied studies that develop better testing methods to predict performance of present and future structures, and c) applied studies that develop potential improvements in the manufacture and processing of steel.

Many of the questions that we now face are the direct result of current and past studies under the Materials Research Program of the Ship Structure Committee. At an earlier time far fewer intelligent questions could be formulated. It may thus be concluded that a major contribution of fundamental research is the knowledge that enables the phrasing of questions that can lead to applicable engineering improvements.

The basic mechanisms of cleavage fracture in steel are not yet well understood. Discrepancies remain between fracture predictions based on the theory of dislocation locking by interstitial atoms and laboratory fracture measurements. For as long as no conceptual model or combination of models consistently explains real fracture behavior, this program should relentlessly probe into the most

promising unknown portions of this question. As new tools, such as thin-film electron microscopy, are developed, their usefulness to the present program should first be established and then applied. The Committee on Ship Steel must also continue to encourage close communications between its investigators and related theoretical and experimental work throughout the world.

The microstructural changes associated with post-welding heat treatment are not now fully known. As this process is often called "thermal stress relieving," it would be important to current practice to establish whether the consequent improvement results from reduction of residual stresses or from structural changes in the material. Substructure changes and the frequency of occurrence of microcracks may need to be included among the factors to be considered.

Steel-making and rolling offer opportunities for the application of new fundamental knowledge to the improvement of steel. When the manner in which manganese influences the ductile-brittle transition is known, control measures may be taken to improve the product. Controlled rolling affords a similar chance to bridge the gap between the research laboratory and the steel mill. Marked deterioration of properties in the plate thickness direction, balanced by improvement in the rolling direction, may be found to be associated with low rolling temperatures and high reduction.

In order to allow evaluation of the quality of thicker plates, testing methods must be studied and developed. This will bring in the broader question of the influence of specimen size and plate thickness on material behavior.

Utilization of higher strength steels in merchant ship hull construction will probably follow the development pattern for warships. The Materials Research Program should thus be examining the kinds of materials that can be considered for this purpose, to determine pertinent properties such as strength, weldability, aging characteristics, and ductile-brittle transition behavior. In this way, possible hazards to the use of a material may be noted in advance of its general introduction. Already the need for structural-grade steel in double thicknesses suggests that either the present grade should be improved in ductility for greater thicknesses or a higher strength material should be used.

Fatigue and brittle fracture have demonstrated enough common characteristics that they may involve some of the same basic mechanisms. A few repetitions of locally high stresses may create a crack from which a high-speed brittle crack may run. It thus becomes important to determine those conditions that promote creation and slow growth of such a crack and those conditions under which a virtually static crack begins to run at high speed. Of key importance to this question for ships may be the influence of corrosion on fatigue and on local deterioration of properties that may permit initiation of a fast crack.

The Design Research Program

In directing its program toward the goal of more rational design of ships, the Committee on Ship Structural Design is recommending not only studies that will add to fundamental knowledge in certain fields but also studies that promise to produce useful quantitative data for incorporation into ship design procedures in the near future.

The needs today in the fundamental areas are greater because so little prior attention has been so directed. In the field of slamming, for instance, the hydrodynamic conditions that cause slamming and the resultant structural response have hardly been defined, even though repairs from slamming damage cost U. S. shipowners many tens of thousands of dollars each year. The Ship Structure Committee Design Research Program must therefore devote a substantial part of its efforts toward defining certain fundamental problems. Until these problems are solved or better understood, the practical goals will continue to remain elusive.

Possible activities include, therefore: 1) fundamental directed research in related fields, 2) studies that will validate the application of research results to practice, 3) studies that could allow refinement of current design methods, and 4) work aimed at a general revision of ship structural design. The last of these has already been stated as the long-term goal of the program, so it may be assumed that all projects contribute to it to some extent.

The brittle fracture studies that have been a vital part of the program should be pushed with vigor, now that some real insight into the influence of damage from prior strain has been gained. As it is quite possible that the mechanism of low-

cycle fatigue is similar in some respects to the gross damage mechanism, although on a smaller scale, this field should be explored fully. Because the designer would like to know unequivocally the stress that a fabricated structure can carry, several projects of the program must study the questions of material property variation during fabrication and service. Although some of these questions are separated into projects they must be considered as part of a single whole: crack initiation and the influence of a notch, crack growth under slow or repeated loads or under dynamic loads, the effects of corrosion and aging, and the influence of welding in producing local residual stresses and changes in the properties of the material in the region of a weld. Neither the present nor the anticipated programs can expect to incorporate all of the needed work, but they must assume responsibility for a part of it.

Any rational design procedure hinges on the accuracy of predicted service conditions. Now that a workable automatic strain recording system has been developed and tried on a ship, second-generation systems should be installed in as many more ships as funds allow. In no other way can the full range of service conditions be determined. The prospect of additional sponsorship for acceleration-recording equipment is indeed welcome, for it adds much to the value of the whole project. Model studies on extreme wave conditions, which will be completed long before sufficient service strain data are available, should be compared with the service data to indicate the validity of similar tests on models of future design.

Of more immediate interest to the designer may be the study to determine the response of a three-dimensional structural configuration to thermal stresses. In the absence of quantitative means for incorporating thermal effects into a design, thermal stresses have in the past been accommodated in the "unknown" portion of the safety factor.

Slamming may be the ship designer's most complex structural problem although the major loads on a ship probably result from the relatively slow changes in wave configuration and ship position. The project on slamming now active under the Design Research Program will probably clarify means for probing this question in such detail that additional projects can in time be

initiated to examine these narrow regions of the unknown. Such growth should be encouraged as much as possible.

The Fabrication Research Program

The aims of the Fabrication Program are the improvement of ship erection and fabrication methods. In any program to improve ship structures, the improvements of materials, of design knowledge and methods, and of fabrication techniques are inextricably interwoven. It is necessary that the knowledge and understanding of fabrication processes be advanced so as to fully exploit the improvements in materials and design knowledge; and conversely, the knowledge should also be complete enough so that when new erection or fabrication processes become attractive, the changes in requirements for materials and design methods imposed by these new processes can be known. Historically, many ship structural problems have been associated with the failure to realize the material and design changes required to utilize new fabrication techniques.

Possible areas of activity include: 1) the design of structural details; 2) fabrication processes and materials (especially welding and weld properties); 3) fabrication quality control and 4) crack arrestor studies.

The subject of structural details long has been one of major interest to the Committee. A book on structural details, intended to focus production attention upon the importance of careful execution of these details will soon be published. This book reflects current knowledge. As our knowledge of plastic fatigue increases, as ships of new configurations such as "all-hatch ships" and ships with unusually heavy framing and plating are designed, and as more and more requirements for the use of both medium and high strength steel and materials such as aluminum and plastics in ship structures appear, considerable review of structural details will be required.

Effort has been devoted, for many years, to the study of residual stresses and their implications in welded structures. As yet, the magnitude and distribution of such stresses, and their effects upon structural behavior are but poorly known. It is important that these effects be defined.

As advances are made in the steels used for ship construction, it is im-

portant that the quality of the welds joining such steels also be improved. It would be most desirable if the strength and toughness of the weld at least matched that of the parent plate. With the improved ship steels, the matter of matching weld and plate deserves study. Even more complex questions arise in case differing plates must be welded, as, for example, high strength steel inserts used in normal ships steel construction. These are subjects of increasing importance in shipbuilding requiring advances in welding technology.

Another area of major interest is that of weld quality control. Weld quality control programs require means of flaw detection and standards of flaw evaluation. Obviously, such standards could rationally be based only on some knowledge of the effects of flaws upon structural behavior. Since quality control measures must meet serious economic considerations, improvements in ship structure through improved quality control require fast, cheap and dependable means of flaw detection, and interpretation and evaluation procedures which have some rather broad acceptance. The Committee maintains a keen continuing interest in this general subject. A survey of shipyard quality control practices had been recommended last year and it is hoped such a survey may be initiated in the near future.

Although the Committee has not sponsored work on crack arrestors in the past few years, it still believes that this is a topic for fruitful investigation. The employment of riveted "crack arrestors" in welded ships has been widely accepted in American shipbuilding, and is required by a number of European owners. It is widely recognized that large economic advantages would accrue if the requirements for riveting could be eliminated. Before such a change would be generally accepted, it would appear necessary that considerably more information on the comparative behavior of welded and riveted crack arrestors must be obtained, perhaps in such quantity that statistical analysis of the laboratory results could be made. In addition, it would appear valuable to obtain full scale verification of the laboratory scale results. The Committee hopes that when funds become available, it will be able to resume work on the crack arrestor question.

ADMINISTRATIVE SUMMARY

ORGANIZATION

The Ship Structure Committee, constituted by the Secretary of the Treasury in 1946, consists of the Engineer-in-Chief, U. S. Coast Guard, as Chairman, and one member each from the Bureau of Ships, U. S. Navy; Military Sea Transportation Service, U. S. Navy; the Maritime Administration, and the American Bureau of Shipping. The Committee was established for the purpose of "prosecuting a research program to improve the hull structure of ships by an extension of knowledge pertaining to design, materials and methods of fabrication."

Subcommittee: Under the direction of the Ship Structure Committee, and acting as a working group for the Committee, is the Ship Structure Subcommittee. The Subcommittee includes two representatives from the agencies of the Committee members, one from the Office of Naval Research, and a project administrator from the Bureau of Ships who serve as members. One or two alternates for each member also participate actively in the Subcommittee's work. These representatives are nominated by their respective organizations for formal appointment by the Ship Structure Committee. Liaison between the Subcommittee and several interested organizations is maintained by representatives from each of these groups. Members, alternates and liaison representatives of the Subcommittee are listed in Appendix D.

Advisory Committees: The principal advisory committees to the Ship Structure Committee are the Committee on Ship Steel and the Committee on Ship Structural Design. These committees were established by the National Academy of Sciences-National Research Council at the request of the Ship Structure Committee for the purpose of providing advice and guidance to the research program. These committees provide guidance and advice for the design and the materials programs of the Ship Structure Committee, while the Subcommittee directly guides the fabrication program. A list of members is given in Appendix E.

A staff consisting of two engineers and two clerical assistants in the Academy-Research Council is assigned to these Academy-Research Council Committees. The current composition of this staff is also given in Appendix E.

Project Advisory Committees: Each research project is advised through a project advisory committee created especially for this purpose. This makes it possible to obtain for each project the advisory services of men particularly well informed in a specific area. A list of members of project advisory committees is given for each research project in Appendices D and E.

Investigators: The investigators performing research have been chosen because of their ability to produce results of value to the Ship Structure Committee program. As will be noted in Appendix A, investigators are located at government laboratories, universities, private institutions and commercial laboratories.

FINANCE

The Ship Structure Committee's agency allocations and obligations for research as listed in Appendix I amounted to a total of $5, 327, 000 for the fifteen years through 1961. The proposed budgets for the four parts of the program for 1962 and 1963 are as follows:

	1962	1963
Design	$ 153,000	$ 245,000
Materials	113,000	155,000
Fabrication	60,000	70,000
Administration & General	76,000	76,000
TOTALS	$ 402,000	$ 546,000

The itemized budget can be found in Appendix J.

OPERATION

Ship Structure Committee Projects: The functions of the various groups working with the Ship Structure Committee research program can be understood by following a hypothetical project from the first expression of need for this research study through to publication of the report of the completed work. Since there are several variations on the usual procedure, this description should not

be interpreted as the only acceptable method of project initiation.

The original idea for needed research may come from anyone: from the users, designers, and builders of ships, potential investigators, members of the Ship Structure Committee or Ship Structure Subcommittee, or members of the advisory committees. Development of the idea takes place in the pertinent principal advisory group (Committee on Ship Structural Design for design projects, Committee on Ship Steel for materials, and Ship Structure Subcommittee for fabrication), which determines how well the project would fit into the program. If the principal advisory group approves, the project is included in its recommendation of projects for initiation.

The Ship Structure Subcommittee, in its capacity as working arm of the Ship Structure Committee for the total research program, first reviews each program with the pertinent advisory committee and investigators, and then examines the technical aspects of each project, new and old, at its annual review meeting. Recommendations from this discussion are incorporated into the budget as prepared by the Executive Group of the Subcommittee. It is this budget that is considered by the Ship Structure Committee at its annual meeting.

From the moment of approval by the Ship Structure Committee of a project, a major responsibility for the project rests with the principal advisory committee. It selects the investigators and appoints an advisory committee for the specific project. This committee follows the work closely, receives all interim reports, meets with the investigators as necessitated by the status of the work, and recommends the future direction of the research. In practice, relationships between members of the project advisory committee and the investigators are most cordial, for the investigators have available to them the thinking and concern of competent men in their field, and they find this a real aid in working toward a common objective.

The investigators conduct the actual research. They also prepare reports for the sponsor upon completion of a coherent series of tests or discrete unit of work, whenever the project undergoes a major change of course, upon a significant discovery, or upon termination of the project. These reports are discussed

with the project advisory committee and a draft is then sent to the chairman of the principal advisory committee. Following approval by the chairman, the draft is sent to the chairman of the Ship Structure Committee for inclusion of his letter of transmittal. The report must also be approved by the President of the National Academy of Sciences-National Research Council if either of its advisory committees is responsible for guidance of the work.

In addition, the investigators are encouraged to prepare papers for presentation before professional society meetings or for submission to technical journals. These papers differ from the reports submitted to the Ship Structure Committee in that they neither require nor imply approval of the Ship Structure Committee, and they usually represent less detailed distillations of research results, perhaps covering work included in several SSC reports. They are thus more suitable for publication because they are relatively short and have had the advantage of a slight time delay which permits them to be better thought out.

Cooperative Activities: The following projects (also listed in Appendix A) have been jointly supported by the Ship Structure Committee and other groups:

a. Project SR-139, "Joint SSC-AISI Study," has been jointly supported by the American Iron and Steel Institute and the Ship Structure Committee. The cost of testing and study at the National Bureau of Standards has been shared equally by the two groups. In addition, the following steel manufacturers have contributed sample steel plates at no cost to the program:

> Bethlehem Steel Company, Inland Steel Company, United States Steel Corporation, Lukens Steel Company, and the Colorado Fuel and Iron Company.

b. Studies under Project SR-141, "Semikilled Steels over 1 in.," have been assisted during the past year by the heat treatment of specimen plates of special semikilled steel by the United States Steel Corporation. Earlier plates from these heats were provided to the Ship Structure Committee for testing and have further demonstrated in the only way possible that high-manganese low-carbon semikilled steel with improved properties can be made on a commercial scale.

c. Project SR-147, "Mill Rolling Practice" has been supplied a number of experimental plates rolled under controlled conditions by the United States Steel Corporation.

d. Project SR-152, "Optimum Composition over 1 1/2 in.," has been fully supported by the Bethlehem Steel Company, through making available to the Ship Structure Committee the investigator's time and the assistance of the Company in obtaining the needed data.

Relations with U. S. Technical Societies: Relations with the Welding Research Council, the Society of Naval Architects and Marine Engineers, the American Society of Mechanical Engineers, the American Welding Society, American Institute of Mining, Metallurgical and Petroleum Engineers, and the American Society for Testing Materials continue to be most effective.

Benefits from research of the Column Research Council have been obtained through participation of the Academy-Research Council staff.

Relations with Activities Abroad: The Ship Structure Committee has continued to foster the exchange of technical information with ship research activities outside the United States. This has been accomplished through the direct exchange of research reports with appropriate foreign activities and individuals, continued support of the International Institute of Welding, and personal discussion with research investigators abroad.

The Committee recognizes the importance of personal contacts among research workers of different countries in improving research. The International Institute of Welding, of which the Ship Structure Committee is a member, has provided an excellent forum for the discussion of research problems of international importance, and has promoted communications between the United States and other member countries of the IIW.

RADM E. H. Thiele, USCG, Chairman of the Ship Structure Committee, LCDR J. D. Crowley, USCG, Secretary of the Ship Structure Committee, Mr. J. B. Robertson, Jr. and Mr. John Vasta, members of the Subcommittee, Dr. D. K. Felbeck of the NAS-NRC staff, Professor W. J. Hall, investigator for Project SR-155, Professor M. Cohen, investigator for Project SR-136, Professor

C. Mylonas, investigator for Project SR-158 and Mr. W. W Offner, Chairman of the Ultrasonics Advisory Committee attended the Annual Congress of the International Institute of Welding in Liege, Belgium in June 1960. Conferences held with ship research and materials research groups in Western Europe provided the Ship Structure Committee with an up-to-date view of a portion of the European activities in these fields.

The 1961 Annual Assembly of the IIW was held in New York City and attended by many persons associated with the Ship Structure Committee program. In association with this Annual Assembly, a series of seminars on problems relating to welded steel structures were held at the University of Illinois and Massachusetts Institute of Technology. These symposia dealt in part with portions of the Ship Structure Committee program, and the entire programs were of great interest to the Ship Structure Committee.

In continuing the pattern established in March 1959, the Committee on Ship Steel and the Committee on Ship Structural Design enjoyed as guest speaker for their annual meetings in March 1961, Dr. Georg Vedeler of Det Norske Veritas, Oslo, Norway. Speaking on the subjects "Various Problems of Immediate Interest to a Ship Classification Man," and "A Naval Architect's Reflections on Some Research Problems with Ship Steel," Dr. Vedeler brought to the members of the advisory committees, to the Ship Structure Committee and the research investigators much valuable experience and background on current structural problems in merchant vessels.

APPENDIX A

SUMMARY OF STATUS OF SHIP STRUCTURE COMMITTEE RESEARCH PROGRAM

a) Projects that have final reports in preparation

SR-128	Ships at Sea
SR-137	Brittle Fracture Mechanics
SR-141	Semikilled Steels over 1 in.
SR-142	Strain Rate and Fracture
SR-146	Structural Design Monograph
SR-148	Design Detail Handbook
SR-152	Optimum Composition over 1 1/2 in.
SR-159	Radiographic Techniques

b) Projects that are active as of April 30, 1961

SR-125	Survey of Current ABS Steels
SR-136	Metallurgical Structure
SR-139	Joint SSC-AISI Study
SR-147	Mill Rolling Practice
SR-149	Low-Cycle Fatigue
SR-150	Residual Stress Determination
SR-151	Met. Variables & D-W Test
SR-153	Ship Response Statistics
SR-154	Slamming Studies
SR-155	Low-Velocity Fracture
SR-157	Model in Extreme Waves
SR-158	Macrofracture Fundamentals
SR-160	Non-graphic Flaw Indicators
SR-161	Temp. Dist. & Thermal Stress
SR-162	Optimum Composition--Experimental

c) Projects proposed for initiation after April 30, 1961

- -	Bending Moment Determination
- -	Shipyard Flaw Evaluation
- -	Weld Metal Toughness

PROJECT NO.: SR-125 MATERIALS PROGRAM
TITLE: Survey of Current ABS Steels
INVESTIGATOR: Mr. E. A. Imbembo
CONTRACTOR: New York Naval Shipyard
ACTIVATION DATE: September 1952

OBJECTIVE: To establish the notch toughness and other related properties of ABS-specified ship plate steels obtained from shipyards and to determine the extent to which present-day steels have been improved over the norms established by the National Bureau of Standards for plates from fractured World War II ships.

PRESENT STATUS: Since the revision of the ABS Rules for Ship Steel the range and average transition temperature for the new material have been found to be -40 to 29 F and 2 F, respectively, for ABS Class B plates, and -46 to 15 F and -8 F, respectively, for ABS Class C plates, as compared with an average of 90 F for World War II steels.

FUTURE PLANS: The experimental work has been completed and a final report is being prepared.

REPORTS:

SSC-99, <u>Notch-Toughness Properties of ABS Ship Plate Steels</u>, by E. A. Imbembo, J. J. Gabriel and N. A. Kahn. First Progress Report, June 10, 1955.

PROJECT NO.:	SR-136	MATERIALS PROGRAM
TITLE:	Metallurgical Structure	
INVESTIGATORS:	Professor M. Cohen Professor B. L. Averbach	
CONTRACTOR:	Massachusetts Institute of Technology	
ACTIVATION DATE:	June 1954	

OBJECTIVE: To determine the influence of metallurgical structure on the brittle behavior of ship steel.

Introduction

In order to study the role of metallurgical structure in the micromechanisms of cleavage, the M.I.T. group has concentrated on the study of a number of important variables that affect the cleavage process. In the past, these have included grain size, composition, and temperature. Currently the major emphasis is on manganese as a compositional variable and on substructure as a structural variable. In addition, new techniques have been developed to facilitate the study of micromechanisms of cleavage.

Effect of Manganese on the Tensile Behavior of Steel

To delineate the effects of manganese on transition behavior, two steels have been investigated one a rimming type with 0.36 weight per cent manganese (project steel E); the other of a semikilled type with 1.30 weight per cent manganese (steel M). Intermediate manganese contents in semikilled grades are now under study. Evidence of cleavage microcrack formation was found in steel E but not in steel M. It appears that crack propagation is the controlling process in ultimate fracture of steel E, whereas crack initiation is the controlling process in steel M. Above the ductility transition temperature, the yield characteristics of the two steels are similar, but the fracture characteristics are quite dissimilar, steel M exhibiting higher fracture stresses and larger ductility. Twinning behavior of the two steels is virtually identical, indicating that manganese does not influ-

ence fracture behavior through the twinning characteristics. Each steel was tested in comparable fine-grained and coarse-grained conditions.

An analogous program of low-temperature testing is now being performed on a semikilled steel of the same carbon content as steel M, but containing 0.69 weight per cent manganese (steel B), simultaneously with the further testing of steel M. It is hoped that this test series will clarify the role of Mn in the low-temperature behavior of mild steel. Each of these steels is being investigated in at least three comparable grain sizes obtained by both furnace cooling and air cooling. The enhancement of ductile-fracture properties attributed to manganese will also be studied in an attempt to determine how manganese exerts its influence; in particular the formation of microcracks in pearlite as well as in ferrite will be examined in greater detail.

Measurements of the grain size and temperature dependence of the lower yield stress for both E and M steels have been found to conflict with the predictions of the theory of dislocation locking by interstitial atoms. However, it is felt that a marked stress and temperature dependence of dislocation velocities can explain this discrepancy. Using this assumption, calculations of the Peierls-Nabarro (friction) stress and dislocation velocities have been made and have resulted in reasonable values. This concept is being extended to the propagation of a cleavage crack.

Effect of Substructure on the Ductile-Brittle Transition

The role of substructure is being studied in an essentially single-phase material so that obscuring side effects can be avoided. Apparently, decreasing subgrain size causes a rise in the ductile-brittle transition temperature in contrast to the effect of grain size. The reason for this influence of substructure is not clear. It is planned to apply varying amounts of tensile deformation and then either to test directly, or after one of several recovery treatments. In addition, some further work on the formation of ductile cracking is planned; in "pure" iron this phenomenon can be studied in the absence of pearlite. This proposed study would seem to have some connection with the processes which occur upon the stress-relief annealing of welds, and may shed some light upon the reasons for

poor performance of those welds which have been "over-stress-relieved" during this operation.

Observations of Microcracks

A plastic replication technique will be used with interrupted tensile tests to reveal surface microstructural changes as a function of amount of strain at various low temperatures. In this way, a history of the deformation preceding fracture can be obtained and the roles of slip, discontinuous yielding, twinning, and microcracking can be investigated in detail. The materials to be used are: high-purity ferrite, B or E steel, and a high-purity Fe-C-Mn alloy.

Cleavage of Iron Single Crystals

An extensive series of observations on cleavage surfaces of iron single- and bi-crystals has been carried out. It is possible to detect the point of origin of fracture by following the path of the cleavage crack as revealed by various surface markings such as twins and river patterns. These observations show that cleavage always originates at a barrier, such as a twin or a grain boundary.

In addition, experiments are now being performed to determine the effect of low-temperature prestrain on the transition behavior of iron single crystals. The object of this program is to change the substructure while eliminating strain aging and deformation twinning to the greatest possible extent. Combined with the measurement of tensile parameters, fracture-surface observations are being made in order to determine whether this prestrain changes the point of origin of fracture. Preliminary results indicate that this treatment raises the transition temperature above that for samples which have been strained comparable amounts and aged.

REPORTS:

SSC-102, The Relation of Microstructure to the Charpy Impact and Low Temperature Tensile Properties of Two Ship Steels, by W. S. Owen, D. H. Whitmore, C. P. Sullivan, B. L. Averbach, Morris Cohen. First Progress Report, June 18, 1956.

SSC-103, The Tensile Yield Behavior of Ship Steel, by Morris Cohen, W. S. Owen and B. L. Averbach. Second Progress Report, September 28, 1956.

SSC-109, Brittle Fracture of Mild Steel in Tension at -196 C, by W. S. Owen, B. L. Averbach and Morris Cohen. Third Progress Report, November 5, 1957.

SSC-114, The Influence of Ferrite Banding on the Impact Properties of Mild Steel, by W. S. Owen, B. L. Averbach and Morris Cohen. Fourth Progress Report, October 6, 1958. Also reprinted in entirety in Welding Journal Res. Supp., vol. 37 no. 8, August 1958, pp. 368-s--374-s.

SSC-120, Where We Stand in Design with Brittle Fracture, by B. L. Averbach. Interpretive Report, February 23, 1960. (Also published in entirety under title: "Physical Metallurgy and Mechanical Properties of Materials: Brittle Fracture", Journal of the Engineering Mechanics Division, Proc. Amer. Soci. of Civil Engineers, vol. 86, no. EM6, Part 1, pp. 29-43 (December 1960).

SSC-133, Effect of Substructure on Cleavage in Iron Crystals, by W. F. Flanagen, Fifth Progress Report, (to be published).

"Some Aspects of Preyield Phenomena in Mild Steel at Low Temperatures," by W. S. Owen, Morris Cohen and B. L. Averbach, Transactions, American Society for Metals, vol. 51 (Digest by J. H. Bechtold appears in Metal Progress, vol. 72, No. 5, November 1957, pp. 212--214.)

"Relation of Charpy Impact Properties to Microstructure of Three Ship Steels," by W. S. Owen, D. H. Whitmore, Morris Cohen, and B. L. Averbach, Welding Journal, Res. Suppl., vol. 36, no. 11, November 1957, pp. 503-s--511-s.

"Brittle Fracture of Mild Steel in Tension at -196 C," by W. S. Owen, B. L. Averbach and Morris Cohen, Preprint No. 41, Transactions, American Society for Metals, 1957.

"Micromechanism of Brittle Fracture in Low Carbon Steel," by G. T. Hahn, B. L. Averbach, Morris Cohen, Welding Journal, Res. Supp., vol. 38, no. 9, September 1959, pp. 367-s--376-s.

"Initiation of Cleavage Microcracks in Polycrystalline Iron and Steel," by G. T. Hahn, B. L. Averbach, W. S. Owen, and Morris Cohen, pp. 91--116 in Fracture, edited by B. L. Averbach, D. K. Felbeck, G. T. Hahn and D. A. Thomas. New York: Technology Press-John Wiley & Sons, Inc., 1959.

PROJECT NO.:	SR-139	MATERIALS PROGRAM
TITLE:	Joint SSC-AISI Study	
INVESTIGATOR:	Mr. C. L. Staugaitis	
CONTRACTOR:	National Bureau of Standards	
ACTIVATION DATE:	October 1954	

OBJECTIVE: To investigate currently produced 3/4-in. ABS-Band 1-1/4-in. ABS-C ship plate steel as obtained from mills, in order to determine its notch toughness and to evaluate those mill factors that may significantly influence this property.

All scheduled experimental work on Project SR-139, jointly sponsored by the American Iron and Steel Institute and the Ship Structure Committee, has been completed.

The initial stage of this investigation was concerned with the problem of developing a suitable sampling scheme capable of properly assessing the degree of variation that may exist between heats, between ingots within heats and also between plates within ingots. Consequently, a decision was made to sample a suitable number of production heats rather than concentrate on just a relative few.

It is to be noted that a separate investigation conducted at the New York Naval Shipyard involves the testing of 51 samples of SR-139 plate material using the van der Veen notched slow bend test. Upon completion of this work, the results will be included in the final report of this project.

Analysis of the data indicates the following:

1. As a consequence of the marked uniformity in mill processing variables and chemical composition within each steel producer, it was not possible to determine statistically their separate effects on the notch-toughness performance of these current production heats.

2. No marked variations in tensile properties were observed for either grades of steel.

3. Both grades of steel exhibit some form of segregation; however, the extremes of such conditions were confined solely to the ABS Class B steel.

4. 95% of the top and center plate positions of the ABS Class B steel exhibited segregation compared to 29% of the bottom plates, more than half of which showed only an extremely faint zone.

5. 65% of the top and center plates of the ABS Class C steel showed evidence of segregation compared to 6% of the bottom plates; however, all such zones were extremely faint and difficult to define.

6. There was no consistent correlation between notch toughness and location of the specimens in the plate, although in individual cases there was a marked variation of values across the plate width.

7. A study based solely on 24 samples of ABS Class C steel contributed by a single producer indicates that differences between heats constitute the primary source of variation and that no particular significance could be attached to ingot locations or plate positions.

8. A similar analysis performed on 15 samples of ABS Class B steel from the same producer indicated that variations between heats and variations between plates are both significant. Because of the sampling arrangement, it was not possible to separate the ingot effect statistically.

9. Plates sampled from the bottom of ABS Class B ingots showed a slightly higher transition temperature (T_{v15}) than the other two plate locations but samples removed from the tops of ingots displayed the largest dispersion of results. No trend was observed for the ABS Class C steel.

10. The mean and standard deviation of T_{v15} for each class of steel are given below:

	$\bar{X}$	SD	n
3/4" ABS Class B Steel	7.5	12.8	39
1 1/4" ABS Class B Steel	-14.3	10.0	49

REPORTS:

SSC-106, Mill Sampling Techniques for Quality Determination of Ship Plate Steel, by C. L. Staugaitis, First Progress Report, January 31, 1958.

Digest of SSC-106 by E. C. Wright in Metal Progress, vol. 75, No. 2, pp. 152--156, February 1959. (Without figures)

PROJECT NO.:	SR-141	MATERIALS PROGRAM
TITLE:	Semikilled Steels over 1 in.	
INVESTIGATORS:	Mr. R. W. Vanderbeck (U. S. Steel Corporation) Mr. J. F. Driscoll (Watertown Arsenal Laboratories)	
CONTRACTOR:	Watertown Arsenal Laboratories	
ACTIVATION DATE:	May 1956	

OBJECTIVE: To study the composition and notch toughness of experimental and production heats of high-manganese low-carbon semikilled ship steel over one inch in thickness.

Completed tests on seven experimental commercial heats of semikilled hot-rolled plate steel containing 0.20 per cent maximum carbon and 1.00 to 1.35 per cent manganese have indicated that the original objective of obtaining an average 15 ft-lb V-notch Charpy transition temperature (V_{15}) of 10 F maximum can be met in plate thicknesses up to about 1 1/4 inch. Actual NDT values of about 20 F have been obtained on this 1 1/4-inch plate.

Tests have now been completed by Watertown Arsenal (V-notch Charpy and drop-weight) and New York Naval Shipyard (van der Veen) on normalized plates from three of the heats, and results are shown in Table I. Normalizing lowered the V_{15} value an average of 13 F and the 1 1/2-inch-thick normalized plates meet the objective of 10 F maximum.

The drop-weight tests on as-rolled and on normalized plate were conducted with slightly different techniques as noted in the table. It is estimated that normalizing lowered NDT about 40 F, which is a large improvement. The NDT value for 1 1/2-inch-thick plate was about 0°F, which is considered quite good and similar to that of hot-rolled ABS Class C steel.

The van der Veen fracture transition temperatures for the normalized plates are judged to be about the same as those for hot-rolled ABS Class B and C steels.

TABLE I. TEST DATA ON NORMALIZED PLATES FROM EXPERIMENTAL COMMERCIAL HEATS OF SEMIKILLED HOT-ROLLED PLATE STEEL

Heat	C	Mn	Plate Thick., in.	15 ft-lb V-Notch Charpy Temperature, F			van der Veen Fracture Appearance Temp., F			Drop-Weight NDT, F		
				Hot-rolled	Norm.	Improvement	Hot-rolled	Norm.	Improvement	Hot-rolled	Norm.	Improvement
71M153	0.12	1.25	3/4	-25	-40	15	34	0	34	-10*	-40*	30
			1 1/4	-10	-13	3	74	44	30	20*	-22*	42
			1 1/2	20	14	6	96	37	59	20*	-30**	50
70L280	0.15	1.18	3/4	-14,2	-13	7	75	64	11	0,0*	-30*	30
			1 1/4	15	14	-1	116	66	50	25***	-22*	47
			1 1/2	30	-13	43	108	59	49	38***	- 4**	42
75L210	0.18	1.27	3/4	-22,2	-22	12	66	75	-9	0,-10*	-30*	25
			1 1/4	-18	-30	12	88	66	22	30***	-22*	52
			1 1/2	18	- 4	22	103	84	19	38***	5**	33
						13.2 avg			29.5 avg.			39 avg.

*NRL normalization procedure; 0.3 inch deflection for 3/4- through 1 1/4-inch-thick specimens.

**0.3-inch deflection on 1 1/2-inch-thick specimens; hence, NDT is somewhat higher than if normalization procedure had been used.

***NDT was only determined for 3/4-inch slices, and the values were consistently from 0 to 10 F. Correction was made to indicate the approximate NDT for full-thickness specimens.

It is concluded that normalized plates of this experimental steel would have about the same notch toughness characteristics as hot-rolled ABS Class C steel.

No further testing is planned. A final report will be prepared.

REPORTS:

SSC-101, Improved Notch Toughness of Experimental Semikilled Steels over 1 in. in Thickness, by R. W. Vanderbeck, August 1, 1956. (Reprinted in its entirety in Welding Journal, Res. Suppl., vol. 37, no. 1, January 1958, pp. 10-s--20-s.)

SSC-108, Notch Toughness Properties of Ship Plate Steel as Evaluated by the van der Veen Notched Slow Bend Test, by E. A. Imbembo and F. Ginsberg, Second Progress Report, August 31, 1959.

PROJECT NO.: SR-142 MATERIALS PROGRAM
TITLE: Strain Rate and Fracture
INVESTIGATOR: Dr. J. M. Krafft
CONTRACTOR: Naval Research Laboratory
ACTIVATION DATE: February 1956
TERMINATION DATE: December 1960

OBJECTIVE: To determine what occurs when steel is stressed at a high strain rate, and how this may relate to brittle fracture.

Results of this project have been presented in three reports submitted to the Committee. Of these, the one entitled "Influence of Speed of Deformation on Strength Properties in the Post Lower Yield Stress Strain Curve of Mild Steel," treats the problem of departures from an equation of state relationship for the stress-strain curve when large variation in straining speed occurs during the strain cycle. Much of the observed behavior can be correlated with the density of slip lines resulting from the various straining rates.

In dynamic testing the lower yield stress is no longer as well behaved and simple a measure of yield strength as in static loading. Much of the observed behavior results from failure of a steady state strain level to be reached in regions traversed by the Lüders band front. A model and numerical analysis which appears to predict experimentally measured deformation patterns is given in "An Interpretation of Lower Yield Point Plastic Flow in the Dynamic Testing of Mild Steel."

Finally, the basic data of this project has been summarized and reported "On Effects of Carbon and Manganese and of Grain Size on Dynamic Strength Properties of Mild Steel." Here the general trends in yield point strain rate sensitivity are found in agreement with effects of composition on the Charpy transition temperature.

REPORTS:

SSC-123, An Interpretation of Lower Yield Point Plastic Flow in the Dynamic Testing of Mild Steel, by J. M. Krafft (to be published). A revised version has also been submitted to Acta Metallurgica for publication.

SSC-127, Influence of Speed of Deformation on Strength Properties in the Post Lower Yield Stress-Strain-Curve of Mild Steel, by J. M. Krafft and A. M. Sullivan, Second Progress Report, December 9, 1960.

SSC-139, On Effects of Carbon and Manganese and of Grain Size on Dynamic Strength Properties of Mild Steel by A. M. Sullivan and J. M. Krafft, (to be published). A revised version has also been submitted for publication in vol. 54 of ASM Transactions.

"Effect of Loading History upon the Yield Strength of a Plain Carbon Steel," by Irwin Vigness, J. M. Krafft, R. C. Smith, presented at Conference on Properties of Materials at High Rates of Strain, Brit. Inst. Mech. Eng., London, April 30, 1957.

"A Relationship between the Fracture Ductility Transition and Strain Hardening Characteristics of a Mild Steel," by J. M. Krafft, A. M. Sullivan, G. R. Irwin, Jour. of Applied Physics, March 1957.

"Brittle Fracture of Ship Steels in Terms of Flow Properties at High Strain Rates," by J. M. Krafft, A. M. Sullivan, Report of NRL Progress, December 1956, pp. 9-18.

"Effect of Grain Size and Carbon Content on the Yield Delay-Time of Mild Steel," by J. M. Krafft and A. M. Sullivan. Transactions American Society for Metals, vol. LI, 1959.

PROJECT NO:	SR-147	MATERIALS PROGRAM
TITLE:	Mill Rolling Practice	
INVESTIGATOR:	Professor W. A. Backofen	
CONTRACTOR:	Massachusetts Institute of Technology	
ACTIVATION DATE:	March 1958	

OBJECTIVE: To determine the relationship of mill-rolling practice to metallurgical structure and properties of ship plate.

Fifteen plates of 1 1/2 in. thickness, all from the same slab of ABS Class B steel, were specially rolled at the U. S. Steel Research Laboratory in Monroeville. The different rolling schedules fit into two categories. After preliminary rolling, twelve plates were reduced essentially isothermally at 1250 F, 1450 F, 1650 F, and 1950 F, so as to finish at 1 1/2 in. with reductions of 15%, 30%, and 60%. The others were rolled according to a practice much like that of Royal Netherlands with temperature falling during the final 30%, finishing at 1250 F, 1450 F and 1650 F. Work to date has involved the study of these as-rolled plates with respect to microstructure, mechanical properties, and especially fracturing characteristics.

Ferrite grain size and shape were measured in rolling (R), transverse (T), and thickness (Z) directions. A somewhat unexpected finding was a maximum difference of only two ASTM grain size units over the entire range of conditions, the largest (mean) ASTM number of 8.65 occurring in plate rolled 60% isothermally at 1450 F. Inclusion counts by the van der Veen method were made and found generally to increase with falling temperature and increasing reduction.

Most of the experimental activity has centered around tension testing over a temperature range from room temperature down to about 50 K (-223 C, -368 F) with specimens taken in both R and Z directions, following the procedure described previously. Twenty or more specimens were required for each

direction in the fifteen plates. Properties of particular interest were the lower yield stress, true fracture stress, and true fracture strain; estimates are being made of the extent of fibrous and crystalline area on the fracture surfaces. A ductility-transition temperature is defined at the intersection of the fracture-stress and yield-stress vs. temperature plots, as reported earlier. Fracturing anisotropy, of interest in the microfissuring argument, is described by the ratio of fracture stress in the Z to that in the R direction, and therefore has a value less than 1 at temperatures above the ductility transition.

The tension data are still not complete in detail, but certain general findings can be reported subject to later modification.

a. Again somewhat unexpected, the fracturing anisotropy ratio is not strongly dependent upon rolling history, the values ranging from about .7 to .6 trending down (increasing anisotropy) with increasing reduction and falling temperature. No clear correlation is apparent between the van der Veen inclusion count and this ratio.

b. Most of the R-direction ductility-transition temperatures lie in the 70-80 K range. The effects of rolling history within this range are largely masked by scatter in the data.

c. With finishing above 1250 F, the Z-direction transitions are in the 80 to 90 K range, or about 10° to 25° above those in the R direction. At 1250 F, however, the temperatures are approximately 100 K (15% reduction), 120 K (30% reduction) and 170 K (60% reduction); in the last case the difference between R and Z directions is about 100 K.

Altogether, the most unusual observations are associated with rolling under the critical, at 1250 F. It was interesting to find in Z-direction tests with plate reduced 60% and 30% that fracture occurred well below the yield stress at test temperatures 30° or more lower than the Z-direction ductility transition. Such a finding has not been made on other plates; perhaps the reason is that tests

have not been made at temperatures sufficiently below the corresponding ductility transitions. Fracturing in R-direction specimens in the same plates is rather striking in that just above the R-transition temperature there have been several cases of a specimen necking down and then fracturing outside of the neck; also, longitudinal splitting along the rolling plane in necked specimens has been found and attributed to transverse (hydrostatic) stress in the neck. There has been some success in relating both observations on R specimens to a normal-stress fracture criterion, the stress in the case of splitting being that for below-yield fracture in the Z direction. Upon pulling R specimens, the cross section becomes elliptical, contraction in the thickness direction being the greater. Such anisotropy in deformation suggests additional effects of a crystallographic texture.

Future Plans

Work remains to be done in completing the current study of as-rolled plates. In addition, experiments have recently been started in which annealing treatments are to be given to the lowest-finishing temperature material in order to separate effects of fibering and residual cold work on fracturing.

In the future, it is planned to do a more limited amount of transition-temperature determination by means of some notch-type test, very likely the Charpy test since it requires only a limited amount of material; such testing would be both practically interesting and important in considering the fissuring contribution to transition temperature in these particular plates. The possibilities in this connection seem quite attractive since plates are available with widely different histories yet rather similar ferrite grain size.

As another subject, a more detailed examination of both the mechanical and crystallographic fibering by microscopy and X-ray diffraction would be carried on, as discussed in the past but not yet undertaken in depth for reasons of time.

REPORTS:

SSC-126, Influence of Hot-Rolling Conditions on Brittle Fracture in Steel Plate, by F. de Kazinczy and W. A. Backofen, First Progress Report, November 10, 1960.

SSC-138, The Influence of Mechanical Fibering on Brittle Fracture in Hot-Rolled Steel Plate," B. M. Kapadia, A. T. English, and W. A. Backofen, (to be published).

PROJECT NO.:	SR-148	FABRICATION PROGRAM
TITLE:	Design Detail Handbook	
INVESTIGATOR:	Professor A. M. D'Arcangelo	
CONTRACTOR:	Virginia Polytechnic Institute	
ACTIVATION DATE:	June 1958	

OBJECTIVE: To assemble and publish the latest information on ship design and fabrication details for the use of the man in the shipyard or drafting room.

Manual Outline

The thirteen sections which were planned originally for the manual have been reduced to seven. A few of the items originally planned for have been eliminated and many others have been consolidated into the remaining sections.

The seven sections of the manual are listed below, together with the number of pages on "ditto" reproduction.

Section	Title	Pages	Illustrations
I	Stresses and Strains on Ships	69	33
II	Minor Openings in Ship Steel Structures	59	27
III	Major Openings in Ship Steel Structures	24	10
IV	Welding Joint Details	110	67
V	Welding Sequence	46	32
VI	Various Details in Ship Steel Structures	67	41
VII	Miscellaneous Structural Data	39	2

It is estimated that the manual will result in a publication of some 250 to 300 printed pages on 6 in. x 9 in. size.

PRESENT STATUS:

a) The first draft of all sections has been written and distributed.

b) The second drafts of sections I and IV have been written and distributed.

c) The third draft of Section II has been written and distributed.

d) Advisory Committee members have commented on all section drafts mentioned in (a), (b) and (c).

e) The manuscript for Sections I through IV is completely ready.

f) There are minor corrections to make to the manuscripts for Sections V through VII.

g) Final illustrations for all sections are ready for the printers except for minor corrections in the illustrations of Sections V through VII.

FUTURE PLANS: The manuscript and all final illustrations will be ready for the printers by the end of spring.

PROJECT NO.: SR-149
TITLE: Low-Cycle Fatigue
INVESTIGATOR: Professor W. H. Munse
CONTRACTOR: University of Illinois
ACTIVATION DATE: August 1958

DESIGN PROGRAM

OBJECTIVE: To evaluate the influence of a few load cycles at high stress levels upon the mechanical properties of ship steels.

A number of factors were outlined in cooperation with the Project Advisory Committee as being important variables that should be given consideration in the program. These included the following: (a) low ductility fracture rather than plastic instability, (b) strain aging (temperature and/or time dependent), (c) various steels, (d) material property variations during the tests, (e) mechanism and rate of crack growth, (f) types of notches or stress concentrations, (g) effect of fully reversed loadings, (h) fatigue lying between one and 10,000 cycles, and (i) relationships of metallographic properties to low-cycle fatigue behavior. A number of these factors have been studied to a limited extent during the past year, thereby making it possible now to narrow the variables in the program somewhat. However, the results from these studies have been responsible for the addition of a number of new questions.

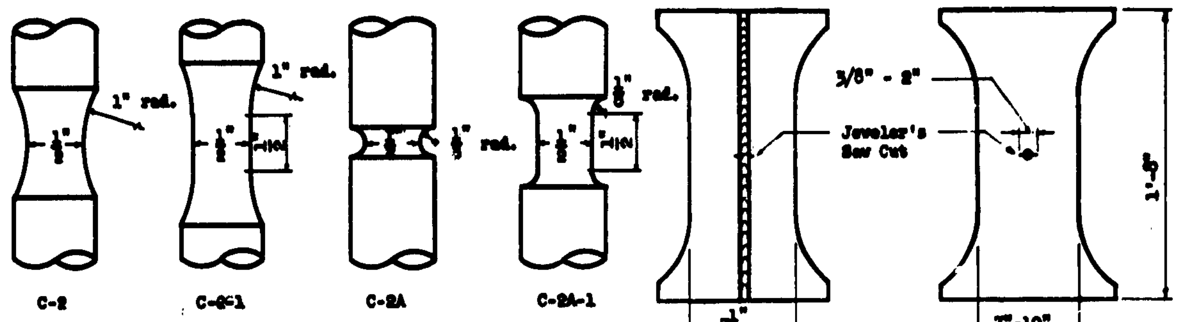
To pursue the low-cycle fatigue program in a systematic manner, the study has been separated into four phases: (1) analysis of the low-cycle fatigue literature, (2) tests of small scale coupon-type specimens, (3) tests of notched flat-plate specimens, and (4) tests of weldments. In the analysis of the literature, an evaluation of the data has been made on the basis of the type of tests, the cyclic rate, stress concentrations, crack propagation, material properties, and low-cycle fatigue hypotheses. The summary report which has been prepared on this phase of the study and is now being edited for publication as an SSC report, indicates that it is desirable to use strain

rather than stress in low-cycle fatigue studies of coupon-type specimens because of the plastic deformation taking place during such tests. In addition, the fatigue hypotheses based on strain, although developed from limited data, exhibit good agreement with the test results and show promise of providing a good indication of low-cycle fatigue behavior for selected loading conditions.

The second phase of the program is concerned with the low-cycle fatigue behavior of coupon-type specimens (see Fig. 1a). These studies include a number of the variables noted above and provide an evaluation of their effect in one-cycle tests, in very low-cycle tests (1 to 50 cycles) and in low-cycle tests (50 to 10,000 cycles). In the studies completed to date it has been found that: (a) geometry is an important factor but does not necessarily have the same effect as in high-cycle fatigue tests, (b) strain aging apparently has little or no effect on the low-cycle fatigue behavior of ABS-C normalized steel, and (c) the direction of the first loading, whether in tension or compression, may have an effect in the very low-cycle range but this effect may decrease as the life increases.

Additional low-cycle constant-strain studies are currently underway on coupon-type specimens and show excellent promise of providing a general hypothesis for the low-cycle fatigue behavior of several of the principal ship steels under various loading conditions. Later an attempt will be made to extend this hypothesis to the more complex members being studied in the program.

The studies of flat plate specimens (Fig. 1b) with a sharp central notch are being used to evaluate the effect of a variety of variables on low-cycle fatigue. Lowering the test temperature, for example, decreases the rate of fatigue crack propagation (increases the life) but, at the same time, may produce brittle fractures when the cracks have propagated through a portion of the member. In other tests it is being found that the type of loading cycle, whether of constant load or constant stress, markedly effects the rate of crack propagation and the low-cycle fatigue behavior of the members. However, these are only the initial tests. Further tests that are currently underway will show the effects of such other factors as stress level, aging, temperature, etc., on the fa-



a) ROUND POLISHED SPECIMENS

b) PLATE SPECIMENS (3/4" THICK)

FIG. 1 TYPES OF SPECIMENS TESTED

TABLE 1

RESULTS FROM TESTS OF WELDED PLATES OF RIMMED STEEL
TESTED UNDER COMPLETE REVERSAL

Specimen	Initial Temp. (deg. F.)	Stress Range ksi	Final Temp. (deg. F.)	No. of Cycles	Remarks
E7016 Welds					
W-1-4	+72	±25	Hot	14,000	Crack evident after 12,000 cycles.
W-1-7	+72	+21 -16	+72	2,900	"Precycling" during machine adjustment.
	-20	±25	+31	23,700	Brittle fracture from 3 3/8 in. Fatigue crack. Total life = 26,600 cycles.
W-1-8	-18	±25	+55	20,900	Shear failure.
E6010 Welds					
W-1-6	+72	±25	Hot	6,400	Crack evident after 4,800 cycles. Apparent slag inclusion at notch.
W-1-5	-20	±25	+30		
W-1-1		±25		13,700	Brittle fracture from 1/8 in. fatigue crack.
W-1-2	-30	±25	-43	22,300	Brittle fracture from 3 1/2 in. fatigue crack.

tigue behavior of the notched flat plate specimens.

The fourth phase of the program is concerned with the low-cycle fatigue behavior of weldments and introduces the variables of residual stress and weld metal into the problem. A few pilot tests at low temperatures have been made on members with a notched (saw cut) longitudinal butt weld (see Fig. 1b) to obtain an indication of the susceptibility of welded fatigue specimens to fracture in a brittle manner. One of these members failed brittlely from a fatigue crack which was only 1/8 in. long; others have fractured brittlely from somewhat longer cracks (see Table 1). Thus, it would appear that the residual stresses and the variations in material properties in these members may have a significant effect on the fatigue and low-temperature behavior of the members.

It should be evident that a great deal of work still remains to be done on the low-cycle fatigue problem. However, the studies to be made during the next year should aid greatly in our evaluation of low-cycle fatigue and in better understanding the role of low-cycle fatigue in the initiation of brittle fractures.

REPORTS:

SSC-137, Low-Cycle Fatigue of Metals-Literature Review, by J. T. P. Yao, (to be published).

PROJECT NO.: SR-150 FABRICATION PROGRAM
TITLE: Residual Stress Determination
INVESTIGATOR: Mr. D. C. Martin
CONTRACTOR: Battelle Memorial Institute
ACTIVATION DATE: October 1958

OBJECTIVE: To determine if hydrogen-induced cracking can be used to study residual-stress patterns in weldments in steel.

Investigations were conducted on simple weldments made with several types of steel, including mild steel (ABS Class B), low-alloy high-strength steel (HY-80), a commercial high-strength heat-treated structural steel, and ultrahigh-strength steel (SAE 4340) to determine whether cracking would occur during hydrogen charging as a result of the residual stress. It was found that systematic crack patterns could be produced in weldments made with SAE 4340 steel plate heat treated to a high-strength level. In steels of lower strength, a systematic crack pattern was not produced by hydrogen charging.

Hydrogen-induced-cracking tests were conducted on several complex weldments made with heat-treated SAE 4340 steel. Complex-butt joints, a circular-groove weld, continuous- and intermittent-fillet joints, and complex structures were tested. Various crack patterns that could be related to the residual-stress distribution were obtained.

Mechanically stress-relieved specimens also were tested to determine whether hydrogen-induced cracking was stress sensitive or plastic-strain sensitive. The test results have shown that the hydrogen-induced cracking was mainly stress sensitive.

The results of the hydrogen-induced-cracking tests have shown that the technique could be used to study the residual-stress patterns in a complex weldment.

Stress-corrosion-cracking tests also were conducted on weldments made with mild steel and several types of high-strength steel. Cracks were obtained in most of the specimens. Systematic crack patterns were observed in the specimen made with the commercial high-strength heat-treated structural steel. The

crack patterns were similar to those obtained in SAE 4340 steel specimens charged with hydrogen. Systematic crack patterns were not observed when other base steels were used.

Analytical investigations of crack patterns were made. Mathematical equations to express the relation between the residual-stress distribution and the crack pattern have been developed. Numerical analyses also were made of crack patterns in simple stress fields.

PROJECT NO.: SR-151 MATERIALS PROGRAM
TITLE: Metallurgical Variables & Drop-Weight Test
INVESTIGATOR: Mr. F. W. Boulger
CONTRACTOR: Battelle Memorial Institute
ACTIVATION DATE: April 1959
TERMINATION DATE: December 1961

OBJECTIVE: To compare the influence of manganese, carbon, and other elements on behavior under different kinds of current tests, with particular emphasis on the NRL drop-weight test.

Since July 1959, ten semikilled and sixteen killed steels have been made and processed in the laboratory. The steels, rolled to 5/8-inch plate using a finishing temperature of 1850 F have grain sizes ranging from 6.7 to 8.4 on the ASTM scale. The steels range in carbon from 0.10 to 0.32 per cent, in manganese from 0.30 to 1.31 per cent, and in silicon from 0.02 to 0.42 per cent. Aluminum contents range from zero to 0.14 per cent. Because of the intentional variations in composition, the tensile strengths range from 51,000 to 82,000 psi.

The data available at this time indicate that:

(1) An increase of 0.10 per cent carbon raises the NDT 19 F and the V_{15} Charpy temperature 16 F

(2) An increase of 0.10 per cent manganese lowers the NDT 2 F and the V_{15} Charpy temperature 7 F

(3) Deoxidation with silicon and aluminum lowers the NDT about 15 F and the V_{15} Charpy temperature 35 F

(4) There appears to be a reasonably good correlation between the NDT and the Charpy transition temperatures defined by 0.015 in. lateral expansion, 15 per cent shear texture or the 15 ft-lb level

(5) The available data do not justify firm opinions about the effect of ferritic grain size on the NDT. Comparison of data for as-rolled and as-normalized plates suggests that an increase of one ASTM grain size is associated with a decrease in NDT of 17 F for killed steels and 31 F for semikilled steels.

The program planned for the proposed continuation period includes:

(1) Additional studies on effect of grain size and heat treatment

(2) Detailed analyses and comparisons of drop-weight and Charpy data from this and other investigations

(3) Production and testing of four or five steels which are expected to provide useful data on the effects of silicon and aluminum

(4) Retests of a few steels which gave unusual transition temperatures.

PROJECT NO.: SR-152 MATERIALS PROGRAM
TITLE: Optimum Composition over 1 1/2 in.
INVESTIGATOR: Mr. Samuel Epstein
CONTRACTOR: Bethlehem Steel Company
ACTIVATION DATE: January 1959
TERMINATION DATE: September 1961

OBJECTIVE: To predict, from available data, the optimum composition for fully killed ship steel in thicknesses over 1 1/2 in.

A revision of the report of this study has been submitted.

A question was asked whether in the Bagsar tests of Class C normalized steel of 3/4 in. up to 4 in. thick plates, the fracture appearance transition temperature of the 3/4 in. plate had come out too low, and that this might have tended to exaggerate the effect of increased thickness. A new set of plates of Class C steel was therefore obtained. A 3/4-in. thick plate was sliced from the surface of a 4-in. thick plate of Class C normalized steel and tested by the Bagsar test. The fracture appearance transition temperature became -15 F instead of the -35 F obtained formerly. While this was slightly higher than in the former result, the difference in the fracture appearance transition temperature in the Bagsar test between the 3/4-in. thick plate and the 4-in. thick plate was still large, namely 75 F. Thus these tests still point to the need for a dependable determination of the geometrical effect of thickness in ship plate.

Lehigh University in its recent study of the geometrical effect of thickness in Class C ship plate has used the Kinzel and the van der Veen test. To study the geometrical effect of thickness while keeping the metallurgy constant, they sliced off the thinner plates from thicker plates of Class C steel. In the Kinzel test (span 13.5 in.) they found a 40 F increase in the ductility transition temperature (at 1% lateral contraction) between 1/2 in. and 1-1/2 in. thickness. In the van der Veen test they found an increase in the fracture appearance transition tem-

perature (50% shear) of 30 F between 1/2 in. and 3 in. thickness. In these tests the geometrical effects of thickness were considerably smaller than in the Bagsar tests, the exact reasons for this not being clear.

A most interesting feature of Lehigh's study was their analysis of the inter-relationships between the dimensions in the bend specimens used, namely the span, thickness, and depth. With a given sharpness of notch the inter-relations are such that the depth of the specimen has to reach a certain critical size before the full effect of increasing thickness in raising the transition temperature is manifested. If this critical depth is not reached, the full rise in the transition temperature as a result of the increased thickness may not be obtained. The effect of increasing length of span was a continued lowering of the transition temperature. The research workers at Lehigh believe that the completion of this analysis of the dimensional effects, coupled with further tests, should result in a dependable determination of the effect of plate thickness in raising the transition temperature of ship plate. They are therefore submitting a proposal for such a study.

Bethlehem has a store of ABS Class C ship plate in thicknesses of 1/2, 3/4, 1, 1-1/2, 2, 3, and 4 in. which would be available for such a study. There are also Class C "Modified" plates of 1 and 1-1/2 in. thickness in this store.

Bars of 1, 2, and 4-in. diam., machined from normalized Class C plates in this store of the same respective thicknesses, have been supplied to Dr. J. M. Krafft of the U. S. Naval Research Laboratory for determination of the G_c fracture toughness parameter of these samples. Dr. Krafft believes this procedure has promise in giving information of value on the thickness effect and is going ahead with these tests.

The final draft of the report "Optimum Composition of Steel Plate over 1-1/2 in. Thick" will now be prepared.

REPORT:

SSC-134, Optimum Composition of Steel Plate over 1-1/2 in. Thick, by S. Epstein (to be published).

PROJECT NO.:	SR-153	DESIGN PROGRAM
TITLE:	Ship Response Statistics	
INVESTIGATORS:	Mr. F. C. Bailey	
	Mr. D. J. Fritch	
CONTRACTOR:	Lessells and Associates, Inc.	
ACTIVATION DATE:	May 1959	

OBJECTIVE: To obtain statistical records of vertical longitudinal wave bending moments experienced by various types of ships operating on different trade routes, with the emphasis being placed on extreme values of external loads. The purpose is to provide information for (a) the direct use of the ship designer, and (b) to test methods of predicting bending moments.

Approach:

The long range study has been divided by the investigators into the following phases:

I. Study of requirements and development of instrument specifications (with Project Advisory Committee).

II. Purchase or development of prototype recorder or counter and lab testing.

III. Installation of prototype aboard ship--short term manned run.

IV. Revise specifications and/or instrument as necessary.

V. Obtain and install instrument on additional ships.

VI. Receive data, rework, analyze, and publish results periodically.

Activity to Date:

The Project Advisory Committee at its February 26, 1960 meeting recommended the use of a magnetic tape analog recording system and a sampling technique. This constituted the end of Phase I of the study. Phases II--IV have

been completed during the period covered by this review.

Development and purchase of components for the system took place during the period from March to September 1960. System assembly and laboratory checkout took place during October 1960. At a November 1, 1960 meeting, the Project Advisory Committee viewed the completed system immediately before installation aboard the first instrumented ship, the S.S. HOOSIER STATE, a C4-S-B5 dry cargo vessel operated by the States Marine Lines of New York City on a North Atlantic run from the U. S. East Coast to Northern European ports.

The system consists of the following items:

1. Tatnall Metalfilm strain gages manufactured by The Budd Company of Phoenixville, Pennsylvania, assembled in stress gages on the inner surface of the port and starboard sheer strakes amidships. The gages were protected by metal moisture-proof housings designed and fabricated by Lessels and Associates, Inc.
2. Wiring from the gages to the instrument room was installed by commercial marine electricians.
3. A Solid-state Strain Gage Power Supply and a Strain Gage Amplifier were purchased from Video Instruments Company, Inc. of Santa Monica, California.
4. An F-M Analog Recording System purchased from Minneapolis-Honeywell Regulator Company, Beltsville, Maryland, provides a 160-hour record on a 10 1/2-in. reel of 1 in. wide magnetic tape.
5. A Programmer was developed and assembled by Lessells and Associates, Inc. to automatically gather the recorded data. Thirty minute records are obtained at regular four hour intervals, and continuous records are obtained as long as stresses greater than a preset level persist.
6. A Motor-Alternator set provides 110 Volt a-c power for the operation of the system from the ships 220 Volt d-c power.
7. A separate tape playback system was purchased from Minneapolis-Honeywell to permit playback of the tapes at the investigators' laboratory.

The ship's officers were instructed in the operation of the recording

system and furnished with data books for the compilation of concurrent data on ship operation and sea conditions. They are accustomed to collecting wind and sea data for the Weather Service. Experience now indicates that the ship's personnel can be expected to maintain suitable data log books and perform such operations as rewinding and changing the tapes on the recorder.

A manned run during an eastward voyage in November and December indicated satisfactory operation. The equipment was operated by ship's personnel on the return westward voyage with satisfactory results. During the second voyage in January 1961, a power supply failure in the tape recorder resulted in complete loss of data. A failure of the strain gage transducer during the third voyage resulted in loss of data after about one-third of the round trip had been completed. The sailing schedule prevented repairs to the transducer.

A calibration of the ship during loading of fuel oil was made in November 1960. Results calculated by the States Marine Lines Marine Department using theoretical section modulus, agreed with the indicated stress within about 7% (calculated 1886 psi, indicated 1750 psi). A preliminary study of the data from the first voyage showed a maximum recorded stress variation of about 7000 psi peak-to-peak under the worst sea conditions encountered.

A proposal to extend the scope of Project SR-153 has been prepared and submitted to the Transportation Corps, U. S. Army. This program would gather long-range statistical data on ship motions affecting ship cargo. It would utilize three additional channels on the tape recorder with acceleration transducers as inputs.

<u>Plans for Future</u>:

The investigators are proceeding with the analysis of data obtained on the first voyage. Analog and digital techniques are being evaluated to determine the most effective and efficient means of obtaining the required response statistics.

Subject to Project Advisory Committee approval, assembly of the second recording unit will be initiated. It is not apparent at the present time that any major revision of the recording system or method of keeping the data logs will be necessary.

PROJECT NO.: SR-154 DESIGN PROGRAM
TITLE: Slamming Studies
INVESTIGATORS: Professor H. A. Schade
Professor R. W. Clough
Professor J. V. Wehausen
CONTRACTOR: University of California, Berkeley
ACTIVATION DATE: March 1960

OBJECTIVE: To initiate an experimental investigation of slamming pressures and structural responses on ships and to develop and check corresponding theoretical predictions.

Review

The original plans included work in three areas: Hull Girder Response, Local Structural Response, and Determination of Loads due to slamming in a seaway. These plans were formed on the basis of a continuing effort extending over four or five years. Since earlier plans for augmenting the staff and enlarging the effort have been temporarily postponed, work, thus far, has been limited largely to Hull Girder Response. The work performed to this time is briefly as follows:

A) Hull Girder Response:
   1. The first stage model, a uniform aluminum beam of "Cross" section, with its instrumentation and support system, has been designed and built.
   2. The beam and its instrumentation have been calibrated.
   3. A digital computer program has been written for the hull girder response, for use in predicting and correlating the response to arbitrary and measured loads.

B) Local Structural Response:
   1. Preliminary plans have been made for the design of a drop-test facility.
   2. An initial survey of bottom damage has been undertaken.

C) Determination of Loads:
   1. A study of the nature of the "slam" loading from pressure records taken

during the sea tests of the Unimak.

Current Status

Hull Girder Response:

Present work is concerned with the response of the uniform beam to a concentrated load having various time histories. As a first loading a step-input function has been applied and the results have been compared with the corresponding digital computer solution.

As a second loading, the calculated "slam" loads obtained as mentioned above have been used as inputs to the computer program for the uniform beam. The design of an impacting device to produce corresponding loading on the model is being worked on and will presently be available. The digital computer program has also been used to determine the response of the Unimak to these calculated loads. Comparison of the uniform beam response and the Unimak response is being made.

Local Structural Response:

Current effort is directed toward evaluating the nature of bottom damage and the character of the structure most frequently damaged. To do this, ship plans of the forward bottom structure of C2, C3, and VC2 class vessels have been obtained. Data on bottom damage, presented in an April, 1960, paper by Mr. H. S. Townsend, before the Metropolitan Section of S.N.A.M.E., are being used in conjunction with visual inspection of ships in local dry docks. In addition, an initial effort is being made to gain qualitative background information on the conditions of velocity and attitude which lead to "slamming."

Future Plans

Hull Girder Response:

Present plans call for further testing of the first stage model "in-air" under impact loadings, with computer solution correlations. On completion of this work, the model will be mounted in an articulated plastic body, of circular section, and floated in water. There, necessary calibrations will be made, followed by a test program which will closely follow that for the model while "in-air."

It should be noted that the first stage model was chosen as a simple "tool" for the development of instrumentation and techniques which could be used in the study of responses of progressively more complex second and third stage models. The second model will be a hollow, rectangular shaper, aluminum extrusion of about 8 ft length. It will be instrumented and supported "in-air" in the same manner as the present model. A test program, similar to that for the first stage model, will be established and the primary interest will be in evaluating the importance of shear deformation in the response of the elementary box-girder. Present plans do not call for testing this model while floating in water.

The third stage model will be of built-up construction, in which the primary elements of the ship girder will be represented. A fourth stage model is planned, in which ship structural characteristics will be represented in some detail. The detail development of this model will be left to a later time, so that model requirements found in the earlier studies may be incorporated.

Local Structural Response:

Preliminary plans have been made for the design and construction of a model drop-test facility, consisting essentially of a stayed mast-with-boom arrangement, with provision for mounting models at the boom end. The facility will be located in a reservoir which is approximately 75 ft square and 5 ft deep. At present there are insufficient funds to support the construction of this facility, however, it is planned that the design and preparations for construction will be pressed to completion so as to avoid delay when such construction funds become available.

Concurrently is planned the continuation of the evaluation of bottom damage and the conditions leading to "slamming." This will be used as a basis of development for a model test program using local structural elements of ship forward-bottom structure.

PROJECT NO.:	SR-155	DESIGN PROGRAM
TITLE:	Low-Velocity Fracture	
INVESTIGATOR:	Professor W. J. Hall	
CONTRACTOR:	University of Illinois	
ACTIVATION DATE:	December 1959	
TERMINATION DATE:	December 1961	

OBJECTIVE: To observe the different nature of the strain pattern associated with slow fracture velocities.

The initial concept for this particular investigation originated from work conducted as a part of SSC Project SR-137, "Brittle Fracture Mechanics," conducted at the University of Illinois. One of the latter phases of Project SR-137 was concerned with studies of brittle fracture propagation in 6-ft wide steel plates containing a residual strain field. These pilot studies indicated that the introduction of a compressive residual strain field resulted in a much slower speed of fracture propagation, a noticeable change in fracture texture, and possible changes in the strain field associated with the propagating fracture, which were considered worthy of further investigation. Accordingly, Project SR-155 was established to study the propagation of brittle fractures in steel plates, with particular emphasis on low-velocity brittle fracture, and the parameters that affect the rate and nature of such fracture propagation. The work during the past year has been concentrated in two major areas, namely, brittle fracture tests of instrumented 6-ft-wide prestressed steel plates, and studies involving the testing of 3-ft wide, and smaller width plate specimens in which the fractures are initiated statically.

With regard to the first area of endeavor, two fully instrumented 6-ft-wide prestressed plate tests, Tests 49 and 50, were made on specimens containing a residual strain field, using the notch-wedge-impact method of initiation. These tests were designed to provide further information concerning the residual strain pattern in the plate resulting from welding of tapered slots, and also to provide information on the behavior of principal strains in the vicinity of the fracture path during propagation. In addition to extensive static strain measurements, the dynamic

response of ten rosette gages were recorded in each of the two tests during the fracture process. The residual strain field produced by welding tapered slots cut in each edge of the plate specimen consisted of a high longitudinal tensile strain at each edge, and a region of longitudinal compressive strain through the center portion of the plate. The average residual compressive strain was approximately -300 microin./in. in Test 49, and about -100 microin./in. in Test 50, at test load. Both specimens were tested at a temperature of -10 F and at an average applied stress of 3000 psi. A partial fracture approximately 54 in. long occurred in Test 49 while in Test 50, with the lower residual compressive strain in the center, the fracture propagated completely across the plate. For purposes of comparison, the significant parameters of all of the 6-ft-wide prestressed plate tests are summarized in Table I.

TABLE I

SUMMARY OF TESTS

6-Ft. Wide Prestressed Plate Specimens

Test No.	Avg. Residual Comp. Strain Microin./in. at test load	Temp. °F	Applied Stress psi	Avg. Speeds-fps max	Avg. Speeds-fps min	Remarks
43	-100	-12	0	—	—	Specimen simply supported on lab floor; 56 in. fracture.
44	0	-12	0	—	—	Plain-plate specimen simply supported on lab floor; first impact - no effect; second impact - 19 in. fracture.
45	-200	-20	3,000	5,500	100	Complete fracture
46	-350	0	3,000	4,500	50	Complete fracture
47	-500	-8	0	3,800	250	Partial fracture, 25 in. long.
48	-300	0	0	4,150	50	Partial fracture, 36 in. long.
49	-300	-10	3,000	5,600	150	Partial fracture, 54 in. long.
50	-100	-10	3,000	6,400	350	Complete fracture

Wells-Type Specimens

Spec. No.	Width-in.	Length-in.	Thick-in.	Temp. °F	Applied Stress psi	Remarks
W36-1	36	36	3/4	-40	9,400	Complete fracture
W25-1	24	36	5/8	-40	40,000	Complete fracture
W25-2	24	36	5/8	-30	18,000	Complete fracture
W26-2	24	36	3/4	-40	9,900	Complete fracture

In general the speed and strain data from the last two tests were similar to that recorded in the earlier tests. In these tests it was found that the highest fracture speeds observed occurred near the initiation edge of the plate in the zone of high residual tensile strain, and the lowest fracture speeds were

recorded through the central portion of the plate in the compressive strain region. In Tests 49 and 50, the maximum speeds observed were in the range of 5500 to 6500 fps, and less than 350 fps, in the respective regions just noted. As a result of the increased instrumentation involving rosettes it was possible to determine in both tests at each gage location the magnitude and direction of the principal strain.

On the basis of the data obtained, it was determined that, in general, the path of the fracture in both tests was normal to the direction of maximum principal strain. Another interesting feature, not observed in any of the earlier tests, was the fact that the strain field very near the tip of the propagating fracture seemed to be approaching a state of biaxiality. This phenomenon could be observed only in data taken from gages in the immediate vicinity of the crack tip and, hence, only limited information is available. In addition, the measurements of strain magnitudes recorded during fracture propagation indicated that the magnitude of the strain field associated with the propagating crack tip diminished as the fracture entered the compressive strain region and decreased in speed. For example, in these tests the peak strains recorded by gages within 1/2 to 1 in. of the fracture was about 500-1000 microin./in., while in an earlier plain plate test in which no residual compressive strain was present, peak vertical strains from 2000-4000 microin./in. were recorded by gages 1/2 to 1 in. away from the fracture.

The second major phase of the program, involving the testing of somewhat smaller specimens, was undertaken to develop a satisfactory technique for statically initiating fractures, and also to provide strain and speed data recorded from fractures which had been statically initiated. For static initiation, two conditions were considered to be necessary, namely, the presence of a sharp notch or flaw as a stress raiser and also the presence of a high residual tensile stress in the region of the flaw and in a direction normal to the plane of the flaw. With these conditions in mind, the first type of specimen investigated was a plate 24 in. wide, 36 in. long and 3/4 in. thick, with a fine saw cut in each edge and a weld bead placed along the edges to produce a residual tensile stress; several

specimens of this type were tested but in none of these edge-notched specimens with this geometry could static initiation be obtained. This particular type of specimen was dropped from further consideration.

Results from tests of Wells-type specimens, in which a longitudinal butt weld joins two halves of a previously notched plate, indicated that this particular type of specimen not only would make possible static initiation, but on the basis of fracture texture observations also would result in low-velocity fractures. Further investigation of this type of specimen was undertaken and, thus far, brittle fracture tests have been conducted on four of these Wells-type specimens. Two of these specimens, one 3 ft wide and the other 2 ft wide, were 3/4 in. thick and the remaining two specimens both 2 ft wide, were 5/8 in. thick. The test temperature of all specimens was approximately -40 F. The average applied stress required to produce fracture in the 3/4 in. specimens were 9400 psi and 9900 psi in the 3-ft and 2-ft-wide specimens respectively, whereas the applied stress required for fracture in the 5/8 in. specimens were 40, 000 psi and 18, 000 psi. The considerable variation in fracture stress for the 5/8-in. specimen could be an indication of a critical thickness effect, especially since the stress required for fracture in the 3/4 in. specimens was consistently low even though the specimen widths were different.

The recording of dynamic measurements were attempted in three of the four tests conducted, but because of the radically different triggering requirements only in the last test were any dynamic records obtained. Data from the last test (Spec. No. W26-2) indicates that the fracture speed was initially in the range of 6000 fps, and slowed down slightly as the fracture neared the edge of the plate.

During the remainder of this calendar year, effort will consist of (a) completing the analysis of the 6-ft-wide prestressed plate data to provide a summary of all of the observations possible from tests of this type, (b) undertaking a number of further tests with Wells-type specimens to attempt to obtain strain and speed records at various stress levels under conditions of static initiation, and (c) some limited studies of notch geometry and thickness effects.

Project SR-155 is scheduled to terminate in December 1961. As a result of our recent studies on this and related programs, we believe there is need for

basic studies to investigate factors not under study at present influencing static initiation and notch nullification, such as thermal stress relief, preheating, notch geometry and aging. From the standpoint of the Ship Structure Committee, in these studies attention would be restricted to structural ship steels. The aim of this program would not be to develop a new type of specimen for evaluating notch geometry, or ranking steels. Instead the program would be directed towards fundamental studies of the effect of such factors as stress, deformation, temperature, thickness of material, and the other factors noted above on initiation and notch nullification, and particularly as related to low stress brittle fracture.

PROJECT NO.:	SR-157	DESIGN PROGRAM
TITLE:	Model in Extreme Waves	
INVESTIGATORS:	Professor E. V. Lewis Mr. J. Dalzell	
CONTRACTOR:	Stevens Institute of Technology	
ACTIVATION DATE:	November 1959	
TERMINATION DATE:	December 1961	

OBJECTIVE: To determine the upper limit of longitudinal seaway bending moments by direct measurement on ship models in tank waves of maximum steepness, supplemented by theoretical calculations.

Review

This project was conceived as a result of recommendations presented in "A Long-Range Research Program in Ship Structural Design," SSC Report 124, November 1959. The experimental plans and the techniques employed follow closely Recommended Research Project 24 of that report.

Since initiation of this project in November 1959, construction and outfitting of models, development of special equipment, and development of wave generating techniques was accomplished. In addition, approximately 30% of the scheduled main experimental work (comprising a total of 450 runs on two models) has been done. The remaining experimental work is scheduled for completion by June 1961. This schedule will allow time for the completion of data reduction, analysis, and submission of the final report by the contract termination date, 31 December 1961.

The primary environmental variable in the investigation is wave steepness, the emphasis being upon regular waves rather than irregular waves although some tests in irregular waves are planned. When the program is completed, it is expected that model data on longitudinal bending moments under wave conditions approaching the most severe to be expected will be obtained for the following ships:

1. Mariner dry cargo ship as designed.

2. Mariner with two radical alterations in weight distribution.
3. Mariner with at least one radical alteration to freeboard.
4. Mammoth Bulk Carrier as designed.
5. USN Destroyer as designed.

In addition, rigid body motions (heave and pitch) are being recorded and analyzed with a view toward correlation with bending moments in extreme waves.

Results to Date

Results so far have been obtained for the Mariner as designed and Mariner with weights concentrated amidships. The second case represents a very large change in weight distribution from design, the longitudinal radius of gyration being reduced 24% to 16% of the length. The experiments so far have shown that:

1. Wave bending moments equal to or exceeding those derived from the standard L/20 static calculation are possible. To our knowledge, model bending moments exceeding the static calculation have not previously been observed.

2. A radical reduction in longitudinal radius of gyration resulted in what appeared to be a more sea-kindly ship (as shown qualitatively by motion pictures) but produced bending moments as much as 75% higher than those observed in the parent Mariner model.

PROJECT NO.:	SR-158	DESIGN PROGRAM
TITLE:	Macrofracture Fundamentals	
INVESTIGATORS:	Professor D. C. Drucker Professor C. Mylonas	
CONTRACTOR:	Brown University	
ACTIVATION DATE:	February 1960	

OBJECTIVE: To study the effect of gross strain upon the mechanical and metallurgical properties of steel and to relate these to steel embrittlement.

Introduction

The work of the past years has shown that typically brittle fractures could be systematically achieved under static loading of steel work-hardened by suitable prestraining and aging. This embrittlement or exhaustion of the original ductility in tension has been achieved by compressive prestrain in three types of specimens: a) notched plates precompressed in their plane (Fig. 1); b) axially compressed round bars; and c) bars subjected to severe bending (Fig. 2). In subsequent reversal of loading (tension of notched plates and of the round bars, and reversed bending of bent bars) the steel fractured at extremely low strains in a typically brittle manner. With static brittle fracture initiation now consistently produced in the laboratory, it is possible to study the factors affecting it.

Present Research Program:

The aims of the present research are:

I. Study of the properties of steel of exhausted ductility, and of the factors affecting it. The important property is the strain to which it can be subjected before fracturing. This property is highly anisotropic, as indicated in precompressed steel by the brittleness in tension parallel to the precompression, and the substantial ductility in a perpendicular direction. The study is not easy. In its simplest form it requires the determination of the strain (strain tensor) which can be withstood in various directions up to fracture. In its most general form it is a

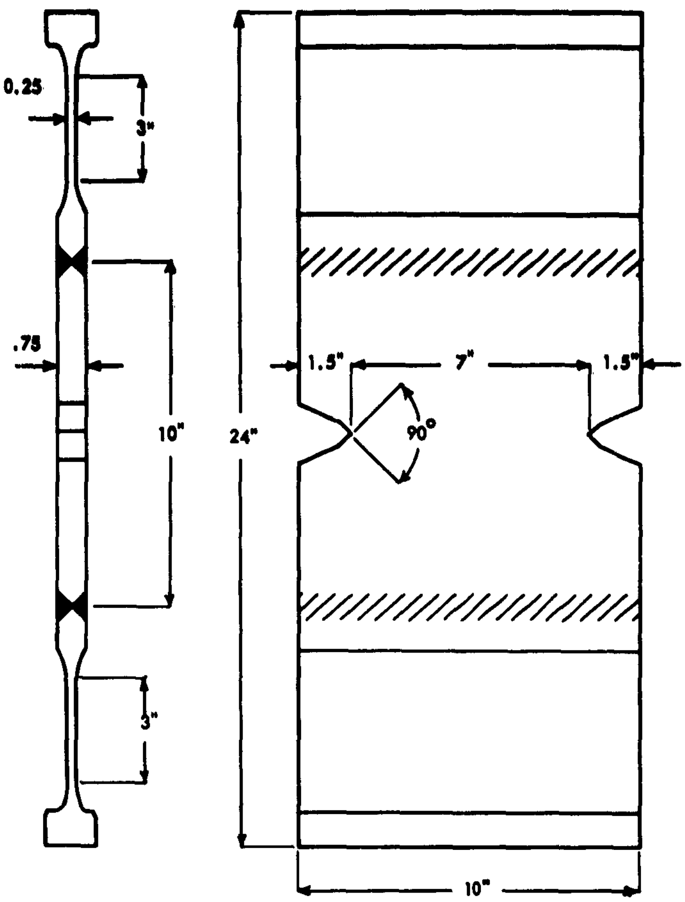


FIG. 1. NOTCHED TEST PLATE WITH PLASTIC HINGE PULL HEADS

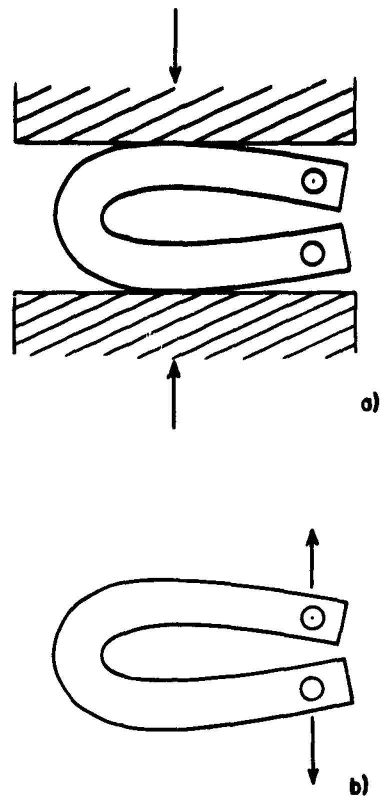


FIG. 2. REVERSED BEND TEST

problem of the whole history of strain and temperature leading to fracture. The only tests planned for the present are in compression at various temperatures, followed by tension in various directions. Likewise, equipment has been designed for tension-torsion tests at various temperatures.

The dependence of the remaining ductility on amount and temperature of precompression, of aging, and of final test temperature has been studied by the following tests:

1. Test for the necessary time and temperature of aging.
2. Over 300 reversed bend tests of 3/4 x 1 x 10 in. bars, aged or unaged, tested at room temperature and at -16 F. Five steels were used.
3. Axial precompression of 3/4 x 3/4 x 8 in. bars, practically uninterrupted up to strains of 50%, in specially

designed equipment.

4. Repeated bending-pulling tests.
5. Repeated bending-pulling tests--complete reversal of the bending.
6. Reversed bend tests--initial bending at various high temperatures followed by unbending at 75 F.
7. Continued bend tests--initial moderate bending at high temperature followed by cooling and continued bending in the same direction at -16 F.

II. Formulation of methods for the assessment of the danger of brittle fracture of steel members, and of the factors affecting it. It is now clear that the ductile or brittle behavior of a structure depends on the relation between the strains developing at the flow limit (when general yielding starts) and the ductility (strain to fracture) of the steel in the same direction and type of stressing. Another exceedingly difficult problem must be solved, in addition to the study of the mechanical properties of prestrained steel previously described. It is the problem of determining the elasto-plastic strain distribution in a structure made of such prestrained steel. At present plans have been made for determining the surface strains of a plate with various notches by using birefringent coatings and by Moirè grids.

In addition it has been possible to study the effect of residual stresses in the various types of fracture tests described. The following tests were done:

8. Tests of notched plates with residual stresses but no notch prestrain.
9. Tests of uniformly precompressed bars without residual stresses.
10. Tests of precompressed notched plates with residual tension removed from the notch-regions.
11. Tests of pre-bent bars with residual tension removed from the intrados.

Conclusions:

The most interesting conclusions are the following:

a. A narrowly determined exhaustion limit exists for bent bars ı jected to reversed bending. Bars strained at room temperatu above this limit behave in a brittle manner and below it in a tile manner. This limit is affected by aging and by the test perature, and its magnitude appears to characterize the tou(of the steel. Summarized results are given in Table I and F Steel compositions are given in Table II. Metallographic te show a strong grain alignment perpendicular to the intrados parallel to the extrados.

b. Accumulation of damage does not appear to occur during a s number of bending-unbending cycles.

c. Residual tension at the region of fracture initiation appeare(have no influence on fracture in the tests performed.

d. Prestraining at high temperatures (up to about 1000 F) signi reduces the exhaustion limit in subsequent tension at 75 F -16 F. The reduction is highest at medium temperatures (Fi where the exhaustion limit has about half the value found i ing at 75 F.

e. Hot extension can radically exhaust the ductility in subseq tension at low temperature. Bars were bent at high tempera extensional strains of about 0.35 at the extrados (radius of then were cooled to -16 F and were subjected to continued The bars fractured in an extremely brittle manner at an addi tensional strain of only 0.02 to 0.03 as indicated in Table phenomenon differs significantly from the so called "blue b which occurs only at high temperature and disappears on c(It also differs appreciably in the direction and appearance responding fractures. This result appears as the most sign this year's work. Actually, exhaustion of ductility by hot provides an explanation of the frequently observed initiatic ture close to welds. Initiation occurs at notches or defect

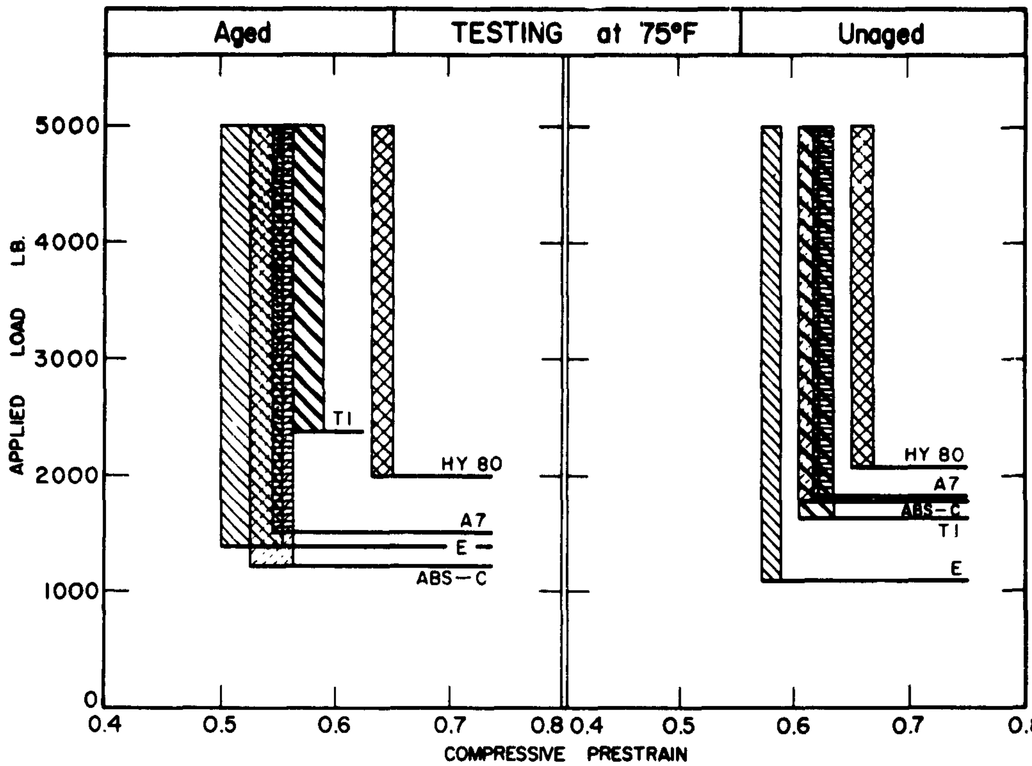


FIG. 3 COLLECTED RESULTS OF UNBENDING TESTS

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TABLE I

Typical Composition and Properties of Steels Used

Steel	C	M	P	S	Si	Cu	Ni	Cr	Mo	Stgth ksi Yield	Stgth ksi Ult.	Elong. 8"	Elong. 2"	Charpy ft.lb.	Charpy °F
E	0.20	0.33	0.013	0.020	0.01	0.18	0.15	0.09	0.02	32	65	36	30	15-3.3	55- -11
ABS-C	0.20	0.62	0.014	0.030	0.20	0.27	--	--	--	43	70	29%	--		
A7	0.26	0.48	0.014	0.032	--	--	--	--	--	35	65	30%	--		
T-1	0.12	0.69	0.011	0.030	0.17	0.31	0.88	0.56	0.44	111	120	--	20%	15	-120
HY-80	--	--	--	--	--	--	--	--	--	80	95	--	24%	140	>-70

TABLE II

Summarized Results of Reversed Bend Tests*

Steel	Tested at -16°F No.	Aged Exh.Limit	No.	Unaged Exh.Limit	Tested at 75°F No.	Aged Exh.Limit	No.	Unaged Exh.Limit	Total No.
E	31	0.40-0.44	39	0.50-0.55	22	0.50-0.55	37	0.57-0.59	129
ABS-C	16	0.50-0.52	16	0.57-0.57	16	0.52-0.56	22	0.60-0.62	70
HY-80	6	0.67-0.70	6	0.63-0.65	14	0.63-0.65	13	0.67-0.69	39
A-7	13	0.46-0.48	16	0.52-0.55	13	0.52-0.55	14	0.61-0.62	56
T-1	8	0.49-0.52	13	0.52-0.53	8	0.56-0.59	9	0.60-0.64	38
									332

* This table includes 49 results already reported in reference

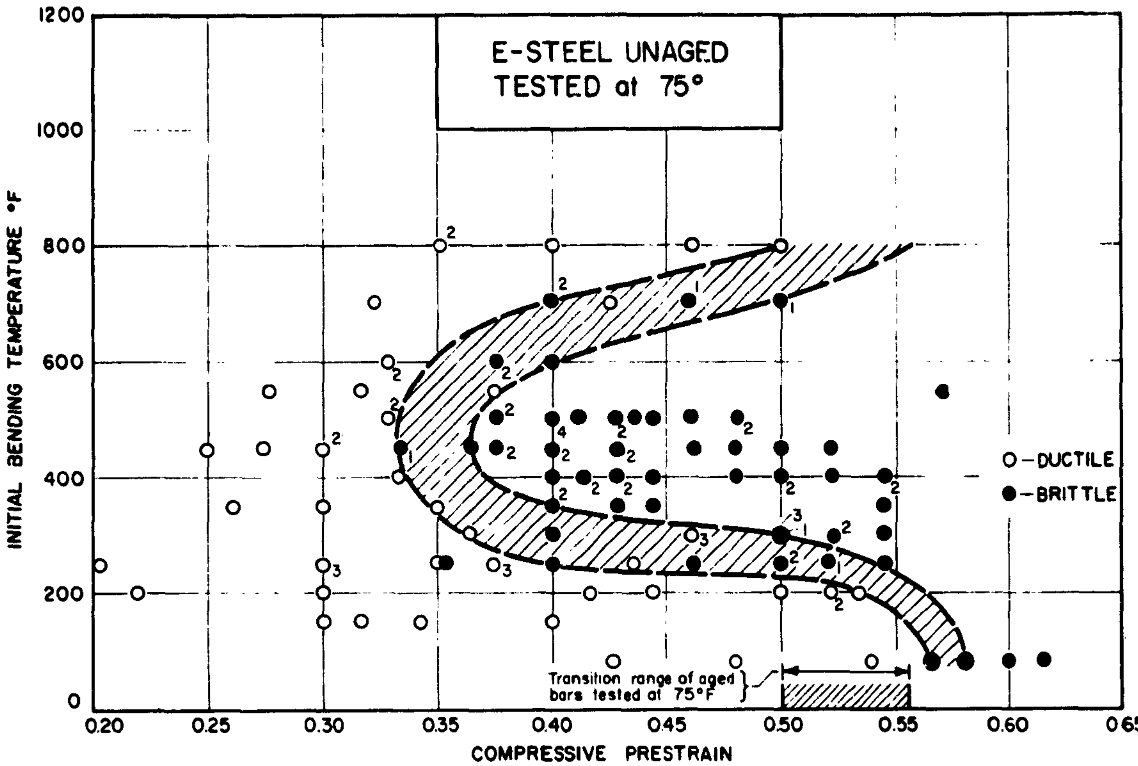

FIG. 4 REVERSED-BEND TESTS OF UNAGED BARS OF E-STEEL PRESTRAINED AT VARIOUS TEMPERATURES

TABLE III

EXHAUSTION OF DUCTILITY IN TENSION FOLLOWING HOT PRESTRAINING IN TENSION

CONTINUED BENDING TESTS OF 0.75 in. THICK BARS OF A-7 STEEL*

Bar	Minutes at 450°F	Initial Bending			Continued Bending			REMARKS
		°F	R (in.)	ε	°F	R (in.)	Δε	
16	35	450°	1.15	0.47	-	-	-	Tension fracture during
13	40	450°	1.43	0.36	-	-	-	initial bending.
10	40	450°	1.48	0.34	-16°	1.43	0.02	Tension fracture during
4	60	450°	1.38	0.37	-16°	1.32	0.03	cold continued bending.
3	60 before initial bending	75°	1.45	0.35	-16°	0.90**	0.37**	No fracture.
7		75°	1.43	0.36	-16°	0.90**	0.36**	
5	60 after initial bending	75°	1.68	0.31	-16°	0.95	0.34	No fracture
6		75°	1.55	0.32	-16°	0.93	0.34	

* All radii of curvature and strains refer to extrados.

** After aging for 1¼ hours at 150°C.

zone close to the weld which was continuously strained in tension during cooling of the weld down to room temperature, and hence also at the most damaging medium temperatures. The presence of a notch or defect in this region puts subsequent high requirements of ducility on the material, which cannot deform sufficiently and fractures.

Future Plans:

The work done up to now is only one step toward the solution of the problem of the static brittle fracture initiation in steel, but already it gives a better understanding of this phenomenon. Thus, it appears that fractures originating at points where cold work has occurred (punched holes, sheared edges, or other deformation) are represented and may finally be quantitatively explained by the phenomenon of exhaustion of ductility in tension by previous precompression. Similarly, fractures originating close to welds, particularly at defects in these regions, may be explained by the phenomenon of exhaustion of ductility in tension by previous hot tension. The investigators wish to pursue their research in the following fields which can significantly advance the knowledge and understanding of brittle fracture:

I. Study of the ductility existing in steel, i.e., of the magnitude and directional dependence of the remaining ductility in prestrained steel, and the effects of type and amount of straining, temperature, and aging. Tests are planned at various temperatures, mainly with bars axially strained in tension or compression, and with bent bars. Other types of straining are also under consideration.

II. Study of the ductility required in a structure to avoid low average stress fracture. Measurements of surface strains with birefringent coatings and Moirè grids are planned.

III. Study of the physical causes of exhaustion of ductility. An important cause, resulting in fractures in all respects similar to service fractures, has now been isolated. It is the exhaustion of ductility by suitable cold or hot prestraining. It is now possible to start studying the metallurgical, and still further, the structural changes which accompany or produce these specific phenomena. This

phase of the research would be executed with the advice and cooperation of a strong team of experts in physical metallurgy and solid state physics, such as Professors John J. Gilman and Joseph Gurland of Brown University.

The investigators wish to pursue research vigorously in all three fields. Unfortunately, on the present research contract this will not be possible even in the first field, or to the extent which the present results seem to require.

REPORTS:

SSC-135, Size Effect in Brittle Fracture of Notched Steel Plates in Tension, by J. H. Ludley and D. C. Drucker, (to be published). Published in Journal of Applied Mechanics, ASME, Brief Note, March 1961, pp. 137-139.

"Viscoelastic Effects in Birefringent Coatings," by P. Theocaris and C. Mylonas, to appear in the Journal of Applied Mechanics.

"A Reversed Bend Test to Study Ductile to Brittle Transition," by J. H. Ludley and D. C. Drucker, Welding Journal Res. Suppl., vol. 39, no. 12, December 1960, pp. 543-s-546-s.

Static Brittle Fracture Initiation Without Residual Stresses, by C. Mylonas, Technical Report, Brown University, February 1961.

"Exhaustion of Extensional Ductility Determined by Reversed Bending of 5 Steels," by K. Rockey, J. H. Ludley and C. Mylonas, in preparation.

"Exhaustion of Ductility in Tension by Previous High Temperature Prestraining," by C. Mylonas and K. Rockey, in preparation.

PROJECT NO.: SR-160 FABRICATION PROGRAM
TITLE: Non-Graphic Flaw Indicators
INVESTIGATOR: Mr. K. F. Sinclair
CONTRACTOR: Naval Radiological Defense Laboratory
ACTIVATION DATE: August 1959

OBJECTIVE: To seek improvements in a filmless radiographic method utilizing conventional radiation sources, and back scattered radiation.

During this year, principal emphasis on the problem has been devoted to: (1) a systematic experimental study of scattering geometry, (2) the development of a simplified theoretical approach permitting the computation of approximate system performance under a variety of circumstances, (3) the application of pulse height analysis and collimation to the problem, and (4) the design and fabrication of a source-transducer assembly approximating the unit ultimately envisioned for practical application.

The experimental scattering geometry studies have shown the best arrangement for maximum sensitivity deep in a metal plate to be one in which the back scattered gamma photons and the incident gamma photons are nearly perpendicular to the test specimen.

A simplified theoretical approach has been evolved based on following the history of singly scattered gamma photons only. Considering the collimation that will actually be used and the additional collimating effect of pulse height analysis, this appears to be a reasonable simplification. Using this technique, the computation of relative scattered intensity as a function of sample plate angle and scattering angle has been completed for a variety of circumstances and the results generally agree with the experimental work.

One of the major stumbling blocks to the ultimate development of a successful system is a physical limitation inherent in the back scattering process. Since the primary and scattered gamma photons are attenuated exponentially as a function of depth in the material while the scattering coefficient at any point in the material remains constant for fixed geometry, the sensitivity of the method

deteriorates markedly with sample thickness. Any practical system must achieve a nearly uniform sensitivity as a function of depth. A method has been evolved which shows promise of significantly reducing this problem. The detector collimator is fashioned so that the detector area seen from a point in the test medium increases with the depth of the point in the medium in such a manner that the loss in sensitivity with depth is offset by the increase in detector area.

The design and fabrication of a "practical" source-transducer assembly has been completed using the experimental and theoretical data previously obtained and incorporating the collimation technique outlined. The design required some compromises since the best scattering geometry did not afford good shielding unless size, weight and over-all efficiency were to be disregarded.

Present plans include acquisition of data with simulated flaws and test plates. Following this work, the assembly will be automated in a simplified fashion to permit direct recorder readout of test specimens.

PROJECT NO.: SR-161 DESIGN PROGRAM
TITLE: Temperature Distribution and Thermal Stress
INVESTIGATOR: Professor J. L. Meriam
CONTRACTOR: University of California, Berkeley
ACTIVATION DATE: July, 1960

OBJECTIVE: To formulate a satisfactory method for calculating ship hull stresses resulting from temperature gradients in three dimensions and having lateral restraint effects included.

Test Facilities

Model: The model (Fig. 1) is being fabricated in three sections. The center test section 10 ft in length is nearing completion (Fig. 2). Each end section under construction is 6 ft long. These sections are rectangular shaped in plan view rather than triangular to facilitate access to test section, attach possible mechanical loading system, and place ballast. Hatch openings will be cut following initial tests as a continuous rectangular section. Double bottom construction, originally planned, has been deleted for simplicity. Extreme care is being used to assure accuracy of construction and uniformity of welding.

Tank: A 1250-gal. water tank, Fig. 3, has been constructed to provide support for the model. Pumps and temperature control tank provide for continuous circulation and prevent stagnation.

Heating System: Hot air will be delivered to and returned from the model through sheet metal ducts. The model will be encased in a plywood box to form an air passage. Connection to the sheet metal pipes will be by canvas ducts. Provision for air temperature control has been made using a steam radiator for heating and a dry-ice air-passage box for cooling. Local temperature gradients will be produced by baffles and heating lamps. Removal of heat absorbed by the water will be through bleed and makeup water with ice in the temperature control tank.

Instrumentation: (Temperature) About 152 out of a possible 288 switch

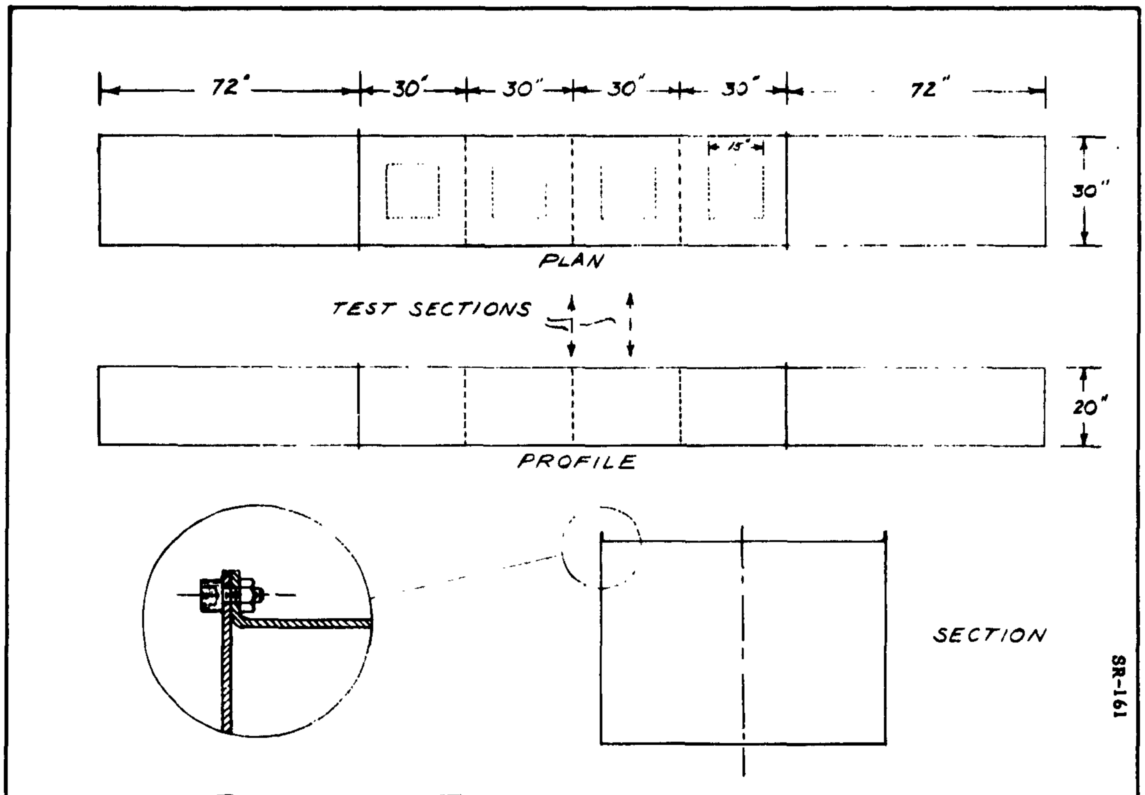

FIGURE 1. THERMAL TEST MODEL

FIG. 2

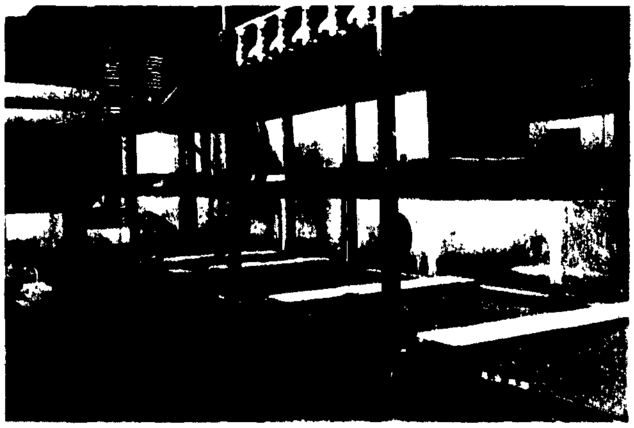

FIG. 3

positions will be utilized for thermocouple readings with a Leeds and Northup Type G Indicator. Additionally, 48 direct-connected thermocouples, separated into three circuits, will be monitored on a 16 point Type G Recorder. Thermocouples have been made and connected to the switching unit.

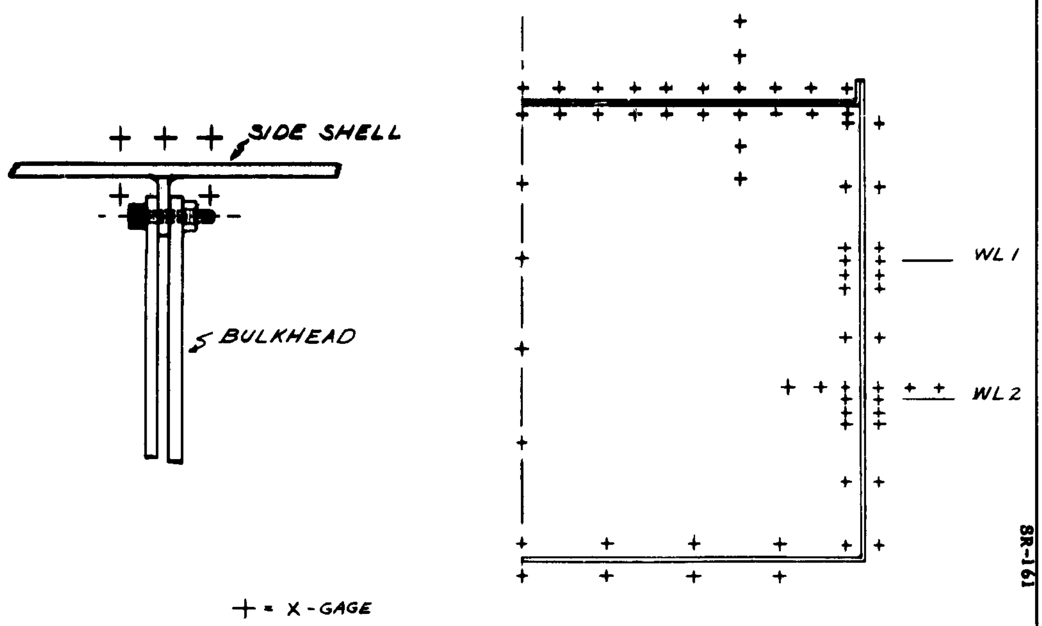

FIGURE 4. APPROXIMATE GAGE LAYOUT BETWEEN AND AT BULKHEAD

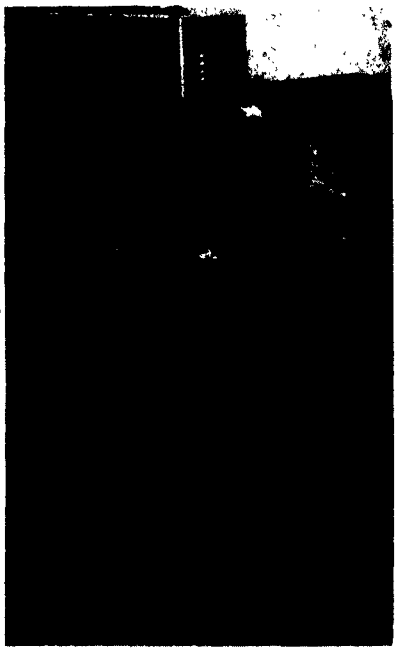

FIG. 5

(Strain) Temperature-conpensated 1/4-in. foil gages (Budd Co. type C-141 and C-141-R2B) are on order for delivery in March. During the past year a strain gage switching and balancing unit has been constructed and tested. The capacity of the balancing and switching unit is sufficient to handle longitudinal and transverse "heart of plate" strain measurements at 144 model locations, Fig. 4. Either the starboard or port side of the model will be instrumented for strain readings. Port and starboard asymmetry will be obtained through reversal of temperature gradients. Strain measurements will be made with a Fairchild Indicator connected

to the switching panel. Both the strain indicator and Type G Indicator are digitized to permit automatic recording of data on paper tape. Figure 5 shows the completed switching unit and the strain and temperature measuring unit.

Test Schedule

Although considerably behind the schedule contemplated earlier, the preparation for the experimental work has proceeded carefully, and it is felt that a highly effective experimental set-up is nearing completion. Model gaging should begin by the end of March, and some experimental results should be obtained by June. The sequence of tests will be determined by experience gained with the preliminary tests using the condition of uniform above-water temperature. Also, the approach to a theoretical solution should be aided by the preliminary experimental results. If superimposed mechanical loading should appear desirable, a system for producing sufficient bending moment independent of ballast and free from stress concentrations near the test section has been designed.

PROJECT NO.: SR-162 MATERIALS PROGRAM
TITLE: Optimum Composition--Experimental
INVESTIGATOR: Dean R. D. Stout
CONTRACTOR: Lehigh University
ACTIVATION DATE: Awaiting Contract

OBJECTIVE: To determine experimentally the optimum composition and/or heat treatment for steel plates up to 4-in. thickness intended for ship construction.

Stage One: Geometrical Effect of Plate Thickness on Notch Toughness

The testing methods will include the van der Veen test, the Bagsar test, and the drop-weight test. Initial tests will make use of a heat of ABS Class C presently available in 1-, 2-, 3-, and 4-in. thicknesses at the Bethlehem Steel Co. Further check tests will be conducted on a modified, 1--1 1/4 per cent Mn, ABS Class C steel. The plates will be normalized before testing.

In the van der Veen test, the plate thickness serves as the width of the bend specimen while the height is normally constant at 2.76 in. In this investigation, the height will be a second variable, including 1/4, 1/2, and perhaps 1-1/2 times the standard height, for all four plate thicknesses. Several series with other span lengths will also be tested. Both ductility and fracture transition temperatures will be determined.

The Bagsar test is an eccentrically loaded, notched tensile test, in which the plate width is normally 6 in., and its thickness that of the source plate. The test width will be varied from 2 through 4, 6, and perhaps 8 in. for the four plate thicknesses. A few series with a longer span will also be included. Transition temperatures will be recorded from lateral contraction and fracture observations.

The drop-weight test is loaded in bending by a falling weight, and the fracture is triggered by a notched hard-facing bead on the tension side. The specimen width is 3-1/2 in. and its height is the original plate thickness. In

these tests the four plate thicknesses will be tested at a constant 3-1/2 in. width, but three span lengths will be included.

Stage Two: Steel Composition and Heat Treatment

The second stage of the program will be concerned with the performance of a series of steels under test conditions selected from the findings of Stage One. The exact steel compositions will be selected later, but they may possibly be a series such as the following:

1. ABS Class C modified to 1.00-1.25 Mn, normalized
2. Steel (1) spray-quenched
3. Steel (1) quenched and tempered
4. Low-alloy steel normalized, or quenched and tempered

These steels would be tested in 1, 2, 3, and 4-in. thicknesses. Charpy V-notch tests would also be conducted.

APPENDIX B

PROJECTS APPROVED FOR INITIATION AT THE 18TH MEETING OF THE SHIP STRUCTURE COMMITTEE JUNE 20, 1961

SHIPYARD FLAW EVALUATION: (Fabrication Program)

To determine the standards presently used in commercial shipyards for the acceptance or rejection of welding by radiography; and to perform a survey of shipyard weld quality control techniques.

WELD METAL TOUGHNESS: (Fabrication Program)

To determine the strength and toughness of weld metal commonly used to fabricate ABS Class B and C steels and to investigate the problems involved in matching the toughness of weld metal and parent plate.

BENDING MOMENT DETERMINATION: (Design Program)

To determine the wave bending moment on typical ships by measuring its value on models at various points along the model length in waves of extreme steepness with models of various current hull forms.

APPENDIX D

SHIP STRUCTURE SUBCOMMITTEE

The Ship Structure Subcommittee performs as the working arm of the Ship Structure Committee in providing continuing and effective operation of the Ship Structure Committee research program.

The Executive Group of the Subcommittee, consisting of one representative from each member agency plus a project administrator from the Bureau of Ships, continues to handle administrative and financial matters. In relieving the Subcommittee of these tasks the Executive Group makes it possible for the Subcommittee to devote its meeting time to technical matters that pertain to advising the Ship Structure Committee on its Fabrication Research Program in addition to reviewing each year the total scope of the work of the Ship Structure Committee.

Members of project advisory committees under the Fabrication Program are listed following the Subcommittee membership. A review of the general functions of project advisory committees is given in Appendix E.

SHIP STRUCTURE SUBCOMMITTEE MEMBERSHIP

Bureau of Ships

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(Alt. Mr. G. A. Pleam)
(Alt. Mr. E. E. Johnson)
Mr. T. J. Griffin
(Alt. Mr. George Sorkin)
Mr. John Vasta

Military Sea Transportation Service

Lieutenant Commander Louis Olivari, USN
Mr. Hubert Kempel

U. S. Coast Guard

Lieutenant Commander J. D. Crowley, USCG - Secretary
Mr. J. B. Robertson, Jr.

Maritime Administration

Mr. V. L. Russo
(Alt. Mr. G. B. Hanes)
Mr. W. G. Frederick
(Alt. Mr. Roger G. Kline)

American Bureau of Shipping

Mr. D. B. Bannerman, Jr.
Mr. G. W. Place

Office of Naval Research

Mr. W. S. Pellini
(Alt. Mr. J. M. Crowley)
(Alt. Mr. Edward I. Salkovitz)

SHIP STRUCTURE SUBCOMMITTEE LIAISON REPRESENTATIVES

National Academy of Sciences-National Research Council

Prof. N. J. Hoff, Chairman - CSSD
Prof. John Chipman, Chairman - CSS
Dr. D. K. Felbeck, Executive Director - CSSD & CSS
Mr. R. W. Rumke, Staff Engineer - CSSD & CSS

American Iron and Steel Institute

Mr. J. Rodger Hamilton
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British Navy Staff

Mr. N. H. A. Warren
Commander G. H. Fuller, RN

Department of the Army, Transportation Corps

Mr. E. C. Seward
Mr. Richard W. Black

Society of Naval Architects and Marine Engineers

Mr. J. P. Comstock

Welding Research Council

Mr. K. H. Koopman, Director
Mr. Charles Larson, Assistant Director

PROJECT ADVISORY COMMITTEES--FABRICATION RESEARCH PROGRAM

SR-148, "Design Detail Handbook, " Virginia Polytechnic Institute

Mr. M. M. Earle, Maryland Shipbuilding & Dry Dock Company, Chairman
Mr. D. B. Bannerman, Jr., American Bureau of Shipping
Mr. R. D. Bradway, New York Shipbuilding Corporation
Mr. Daniel Costello, Jr., Ingalls Shipbuilding Corporation
Mr. G. B. Hanes, Maritime Administration
Mr. C. R. Horton, Jr., Dravo Corporation
Mr. A. M. Johnson, Bureau of Ships
Mr. W. E. Magee, U. S. Coast Guard Headquarters
Mr. R. H. Miller, Manitowoc Shipbuilding, Inc.
Mr. F. L. Pavlik, Sun Shipbuilding & Dry Dock Company
Professor A. M. D'Arcangelo, Investigator

SR-150, "Residual Stress Determination, " Battelle Memorial Institute

Mr. LaMotte Grover, Air Reduction Sales Company, Chairman
Professor A. E. Flanigan, University of California, L. A.
Mr. L. J. Larson, Allis-Chalmers Manufacturing Company
Professor W. R. Osgood, Catholic University
Mr. D. C. Martin, Investigator

SR-160, "Non-graphic Flaw Indicators, " Naval Radiological Defense Laboratory

Mr. Harold Hovland, Industrial X-Ray Engineers, Chairman
Dr. J. I. Bujes, Naval Ordnance Test Station
Mr. W. W. Offner, X-Ray Engineering Company
Captain D. V. Reardon, USCG
Dr. V. J. Salmon, Stanford Research Institute
Mr. Kenneth Sinclair, Investigator

Ultrasonics Advisory Committee

Mr. W. W. Offner, X-Ray Engineering Company, Chairman
Mr. C K. Gordon, Ingalls Shipbuilding Corp.
Mr. M. S. Northup, Esso Research & Engineering Company
Mr. V. L. Russo, Maritime Administration

APPENDIX E

COMMITTEE ON SHIP STRUCTURAL DESIGN
COMMITTEE ON SHIP STEEL

Advisory Committees of the National Academy of Sciences-National Research Council continue to aid in the effective prosecution of the research program sponsored by the Ship Structure Committee by advising on the planning, direction, and interpretation of research work. The Academy-Research Council committees that perform these functions are the Committee on Ship Structural Design and the Committee on Ship Steel. The Committee on Ship Structural Design has advisory cognizance of an active program covering the general fields of ship structural design, dynamic behavior of ships, and brittle fracture mechanics. The Committee on Ship Steel of the Academy-Research Council advises the Ship Structure Committee on maintenance and conduct of a research program on methods for improving ship steels through research in fundamentals of steel behavior and development of production of better steels.

A total of 20 Project Advisory Committees organized under the Committee on Ship Steel, Committee on Ship Structural Design, and Ship Structure Subcommittee have been active during the year in advising specific projects under the Ship Structure Committee program. Each advisory committee provides direct administrative and technical guidance to one or two projects, and meets periodically with the investigators as required by the needs of the project. In addition, various project advisory committees perform their tasks individually under such circumstances as reviewing technical progress and final reports prepared by investigators for publication. Much of the contribution by members of these committees is through thought and discussion of the research problems between meetings. These men contribute substantially to the program through study of investigators' interim reports and through periodic review and criticism of the methods and objectives of the projects.

Staff: The staff of the National Academy of Sciences-National Research Council provides a mechanism for carrying out the responsibilities of the Com-

mittee on Ship Steel and the Committee on Ship Structural Design, which have been asked to advise and administer the Materials and Design Programs respectively. At the request of the Subcommittee, the staff also assists in technical administration of the Fabrication Program. Operation of the research advisory committees involves functions such as arranging for meetings of the advisory committees with the investigators when necessary, preparing investigators' reports for publication, writing analyses of Ship Structure Committee research work, studying possible future research, providing any needs of investigators that will expedite their projects, and maintaining close technical contacts with other individuals and organizations working in related fields of research. On the basis of annual recommendations of the Committee on Ship Steel and the Committee on Ship Structural Design, the staff prepares the proposed Materials and Design Research Programs for the coming year.

The current staff is listed below:

Dr. David K. Felbeck, Executive Director
Mr. Richard W. Rumke, Staff Engineer
Mrs. Gertrude W. Allen, Administrative Assistant
Miss Marie Francis, Secretary

COMMITTEE ON SHIP STRUCTURAL DESIGN

Chairman:

Professor N. J. Hoff
Head, Department of Aeronautical Engineering
Stanford University
Stanford, California

Vice Chairman:

Mr. M. G. Forrest
Vice President - Naval Architecture
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Professor William Prager
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Professor Dana Young
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New Haven, Connecticut

PROJECT ADVISORY COMMITTEES--DESIGN RESEARCH PROGRAM

SR-130, "Brittle Fracture Mechanics," Brown University
SR-137, "Brittle Fracture Mechanics," University of Illinois

Professor N. J. Hoff, Stanford University, Chairman
Professor D. S. Clark, California Institute of Technology
Professor Morris Cohen, Massachusetts Institute of Technology
Mr. F. J. Feely, Jr., Esso Research and Engineering Company
Mr. Martin Goland, Southwest Research Institute
Dr. G. R. Irwin, Naval Research Laboratory
Professor E. Orowan, Massachusetts Institute of Technology
Professor W. R. Osgood, Catholic University
Professor M. P. White, University of Massachusetts
Professor D. C. Drucker, Investigator, SR-130
Professor Costa Mylonas, Investigator, SR-130
Professor W. J. Hall, Investigator, SR-137
Professor N. M. Newmark, Investigator, SR-137
Liaison: Mr. V. L. Russo, Maritime Administration

SR-146, "Structural Design Monograph," Southwest Research Institute

Mr. E. M. MacCutcheon, Naval Civil Engineering Laboratory, Chairman
Professor H. H. Bleich, Columbia University
Dr. C. O. Dohrenwend, Rensselaer Polytechnic Institute
Professor N. J. Hoff, Stanford University
Professor B. G. Johnston, University of Michigan
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SR-149, "Low-Cycle Fatigue," University of Illinois

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Mr. J. A. Bennett, National Bureau of Standards
Professor B. J. Lazan, University of Minnesota
Professor J. D. Lubahn, University of Wisconsin
Professor Dana Young, Yale University
Professor W. H. Munse, Investigator
Professor R. J. Mosborg, Investigator

PROJECT ADVISORY COMMITTEES--DESIGN RESEARCH PROGRAM (Continued)

SR-153, "Ship Response Statistics," Lessells & Associates, Inc.

Dr. C. O. Dohrenwend, Rensselaer Polytechnic Institute, Chairman
Dr. C. S. Cox, Scripps Institute of Oceanography
Professor J. P. Den Hartog, Massachusetts Institute of Technology
Dr. N. H. Jasper, David Taylor Model Basin
Professor E. V. Lewis, Stevens Institute of Technology
Mr. R. L. McDougal, Lockheed Aircraft Corp.
Mr. F. C. Bailey, Investigator

SR-154, "Slamming Studies," University of California, Berkeley

Dr. H. N. Abramson, Southwest Research Institute, Chairman
Professor Louis Landweber, State University of Iowa
Mr. R. T. McGoldrick, David Taylor Model Basin
Mr. M. J. Turner, Boeing Airplane Company
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Professor H. A. Schade, Investigator
Professor R. W. Clough, Investigator
Professor J. V. Wehausen, Investigator
Liaison: Mr. V. L. Russo, Maritime Administration

SR-155, "Low-Velocity Fracture," University of Illinois

Professor Dana Young, Yale University, Chairman
Mr. J. S. Clarke, Esso Research & Engineering Company
Dr. J. M. Frankland, National Bureau of Standards
Dr. J. M. Krafft, Naval Research Laboratory
Professor W. J. Hall, Investigator

SR-157, "Model in Extreme Waves," Stevens Institute of Technology

Mr. M. G. Forrest, Gibbs & Cox, Inc., Chairman
Mr. Harold Acker, Bethlehem Shipbuilding Division
Mr. T. M. Buerman, Gibbs & Cox, Inc.
Professor C. Ridgely-Nevitt, Webb Institute of Naval Architecture
Professor W. J. Pierson, Jr., New York University
Mr. J. F. Dalzell, Investigator
Professor E. V. Lewis, Investigator

PROJECT ADVISORY COMMITTEES--DESIGN RESEARCH PROGRAM (Continued)

SR-158, "Macrofracture Fundamentals," Brown University

Professor W. R. Osgood, Catholic University, Chairman
Professor W. J. Hall, University of Illinois
Professor N. J. Hoff, Stanford University
Mr. J. A. Kies, Naval Research Laboratory
Professor P. M. Naghdi, University of California
Professor D. C. Drucker, Investigator
Professor Costa Mylonas, Investigator

SR-161, "Temp. Dist. & Thermal Stress," University of California, Berkeley

Professor William Prager, Brown University, Chairman
Professor B. A. Boley, Columbia University
Mr. John P. Comstock, (Retired)
Mr. Samuel Levy, General Electric Company
Mr. R. H. Rogers, Esso Tankers, Inc.
Professor J. L. Meriam, Investigator

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Professor John Chipman
Professor of Metallurgy and Head of
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Massachusetts Institute of Technology
Cambridge 39, Massachusetts

Vice Chairman:

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Applied Research
United States Steel Corporation
Pittsburgh 30, Pennsylvania

Members:

Dr. C. S. Barrett
Institute for the Study of Metals
University of Chicago
Chicago 37, Illinois

Mr. Paul Ffield, Assistant Manager of Research
Bethlehem Steel Company
Bethlehem, Pennsylvania

Professor Maxwell Gensamer
604 School of Mines
Columbia University
New York 27, New York

Dr. J. R. Low, Jr.
Metallurgy Research Unit
Research Laboratory, General Electric Company
Schenectady, New York

Mr. T. S. Washburn, Manager
Quality Control Department
Inland Steel Company
East Chicago, Indiana

Mr. T. T. Watson, Director of Research
Lukens Steel Company
Coatesville, Pennsylvania

Liaison Representatives:

Mr. G. W. Place
American Bureau of Shipping
45 Broad Street
New York 4, New York

Mr. W. S. Pellini
Naval Research Laboratory
Department of the Navy
Washington 25, D. C.

PROJECT ADVISORY COMMITTEES--MATERIALS RESEARCH PROGRAM

SR-136, "Metallurgical Structure," Massachusetts Institute of Technology
SR-142, "Strain Rate and Fracture," Naval Research Laboratory

Dr. J. R. Low, Jr., General Electric Company, Chairman
Dr. C. S. Barrett, Institute for the Study of Metals
Mr. J. H. Bechtold, Westinghouse Research Lab.
Dr. L. S. Darken, U. S. Steel Corporation
Professor Maxwell Gensamer, Columbia University
Professor Morris Cohen, Investigator, SR-136
Professor B. L. Averbach, Investigator, SR-136
Dr. J. M. Krafft, Investigator, SR-142

SR-139, "Joint SSC-AISI Study," National Bureau of Standards

Dr. W. J. Harris, Jr., National Academy of Sciences, Chairman
Mr. F. W. Boulger, Battelle Memorial Institute
Professor Morris Cohen, Massachusetts Institute of Technology
Mr. Samuel Epstein, Bethlehem Steel Company
Dr. R. F. Miller, U. S. Steel Corporation
Mr. J. P. Sheehan, Armour Research Foundation
Dr. J. W. Spretnak, Ohio State University
Professor R. D. Stout, Lehigh University
Mr. T. S. Washburn, Inland Steel Company
Mr. T. T. Watson, Lukens Steel Company
Dr. W. J. Youden, National Bureau of Standards
Mr. C. L. Staugaitis, Investigator
Liaison: Mr. W. S. Pellini, Naval Research Laboratory
Liaison: Mr. R. E. Wiley, Office of Naval Research

SR-141, "Semikilled Steels over 1 in."

Mr. M. W. Lightner, U. S. Steel Corporation, Chairman
Dr. W. J. Harris, Jr., National Academy of Sciences
Mr. W. S. Pellini, Naval Research Laboratory
Mr. T. T. Watson, Lukens Steel Company
Mr. T. S. Washburn, Inland Steel Company
Mr. R. W. Vanderbeck, U. S. Steel Corporation, Investigator
Liaison: Mr. G. W. Place, American Bureau of Shipping

PROJECT ADVISORY COMMITTEES--MATERIALS RESEARCH PROGRAM (Continued)

SR-147, "Mill Rolling Practice," Massachusetts Institute of Technology

Mr. T. S. Washburn, Inland Steel Company, Chairman
Mr. J. L. Giove, U. S. Steel Corporation
Mr. J. R. LeCron, Bethlehem Steel Company
Mr. T. T. Watson, Lukens Steel Company
Dr. Cyril Wells, Carnegie Institute of Technology
Professor W. A. Backofen, Investigator

SR-151, "Metallurgical Variables and Drop-Weight Test," Battelle Memorial Institute

Dr. J. R. Low, Jr., General Electric Company, Chairman
Dean R. D. Stout, Lehigh University
Mr. R. W. Vanderbeck, U. S. Steel Corporation
Mr. T. S. Washburn, Inland Steel Company
Mr. F. W. Boulger, Investigator

SR-152, "Optimum Composition over 1 1/2 in.," Bethlehem Steel Company

Mr. T. T. Watson, Lukens Steel Company, Chairman
Mr. F. W. Boulger, Battelle Memorial Institute
Professor Maxwell Gensamer, Columbia University
Dr. John Gross, Lehigh University
Mr. R. W. Vanderbeck, U. S. Steel Corporation
Mr. Samuel Epstein, Investigator

SR-162, "Optimum Composition--Experimental," Lehigh University

Mr. T. T. Watson, Lukens Steel Company, Chairman
Mr. Otis Carpenter, Babcock & Wilcox Company
Mr. Samuel Epstein, Bethlehem Steel Company
Mr. Walter Fleischman, Knolls Atomic Power Laboratory
Dr. John Gross, U. S. Steel Corporation
Dean R. D. Stout, Investigator

APPENDIX F

MEETINGS

Ship Structure Subcommittee. In the period covered by this report, the Subcommittee has met four times. Two meetings were devoted to the Design Program, and one meeting each for the Fabrication and Material Programs.

Executive Group of SSSC. The Executive Group met once in the period covered by this report to handle administrative and financial matters.

Committee on Ship Steel. A meeting was held September 27, 1960 to consider new research. A two-day meeting was held on March 29 and 30, 1961, which was devoted to reports and presentation by investigators and discussion from Committee members. As a part of the second day's meeting, the Committee prepared specific recommendations for the Materials Research Program.

Committee on Ship Structural Design. A meeting was held October 11, 1960 to consider new research. On January 12, 1961 the chairman and vice chairman attended the meeting of the Ship Structure Subcommittee. A two-day meeting was held on March 27 and 28, 1961, to hear reports from the research investigators and permit discussions of the reports as presented. The second day was devoted to future plans of the committee and preparation of specific recommendations for new work and levels of effort for the future.

Project Advisory Committees. There have been twenty-two meetings of project advisory committees with their investigators to provide administrative and technical guidance to their respective projects.

APPENDIX G

REPORTS

Reports Published and Distributed by the Ship Structure Committee between May 1, 1960 and April 30, 1961

SSC Report	SR Project	
121	127	Manual of Isotope Radiography by E. L. Criscuolo, D. Polansky and C. H. Dyer, Final Report, May 23, 1960.
122	134	Behavior of Riveted and Welded Crack Arrestors by R. J. Mosborg, Final Report, August 31, 1960.
126	147	Influence of Hot-Rolling Conditions on Brittle Fracture in Steel Plate by F. de Kazinczy and W. A. Backofen, November 10, 1960.
127	142	Influence of Speed of Deformation on Strength Properties in the Post Lower Yield Stress-Strain Curve of Mild Steel by J. M. Krafft and A. M. Sullivan, 2nd Progress Report, December 9, 1960.
128	--	Influence of Steel-Making Variables on Notch Toughness by J. H. van der Veen, Special Report, June 27, 1960.
130	137	Studies of Brittle-Fracture Propagation in Six-Foot-Wide Steel Plates with a Residual Strain Field by F. W. Barton and W. J. Hall, 6th Progress Report, April 3, 1961.

Annual Report from the Ship Structure Subcommittee to the Ship Structure Committee. Washington: Ship Structure Committee, May 1, 1960.

Outside Reports Distributed by the Ship Structure Committee

Proposed Program for Maritime Administration Research prepared by Maritime Research Advisory Committee, NAS-NRC, vols. I and II, 1960.

"Longitudinal Strength and Minimum Weight," by Jan R. Getz. European Shipbuilding, no. 5, vol. IX, 1960, pp. 98--120.

Final Reports Planned for Publication

Report SSC-	Project SR-	Title
131	137	Brittle Fracture Propagation in Wide Steel Plates by W. J. Hall, S. T. Rolfe, F. W. Barton, and N. M. Newmark
132	159	The Feasibility of X-Ray Inspection of Welds Using Back-Scattered Radiation by E. Criscuolo, C. H. Dyer and D. P. Case
134	152	Optimum Composition of Steel Plate over 1 1/2 in. Thick by Samuel Epstein
139	142	On Effects of Carbon and Manganese Content and of Grain Size on Dynamic Strength Properties of Mild Steel by J. M. Krafft and A. M. Sullivan

PUBLISHED REPORTS AND PAPERS RESULTING FROM SHIP STRUCTURE COMMITTEE SPONSORED WORK

"Tough Ship Plate" by William J. Harris, Jr., and Clyde Williams. A report on work done under SSC Project No. SR-135, published in Metal Progress, vol. 75, no. 4, pp. 66-71 (April 1959).

Some Observations on the Brittle Fracture Problem by G. M. Boyd. Committee on Ship Steel Special Report published as WRC Bulletin No. 57, April 1960.

Studies of the Strain Distribution in Wide Plates during Brittle Fracture Propagation by S. T. Rolfe, T. M. Lynam, and W. J. Hall, A report on work done under SSC Project No. SR-137, distributed as Document No. IX-259-59 of the International Institute of Welding, May 23, 1960.

"Evaluation of Weld-Joint Flaws as Initiating Points of Brittle Fracture" by R. P. Sopher, A. L. Lowe, Jr., and P. J. Rieppel. A report on work done under SSC Project No. SR-131, reprinted in full, U. S. Office of Technical Services, No. PB 161323 and reviewed in Review of Metal Literature, July 1960, p. 34.

"Weld Flaw Evaluation" by S. T. Carpenter and R. F. Linsenmeyer. A report on work done under SSC Project No. 126, reprinted in full, U. S. Office of Technical Services, No. PB 161322 and reviewed in Review of Metal Literature, July 1960, p. 34.

"Preliminary Studies of Brittle Fracture Propagation in Structural Steel" by W. J. Hall, W. G. Godden, and O. A. Fettahlioglu. A report on work done under SSC Project No. SR-137, reprinted in full, U. S. Office of Technical Services, No. PB 161325 and reviewed in Review of Metal Literature, July 1960, p. 34.

"Welding Fabrication and Design" by John Bennett. A report on work done under SSC Project No. SR-144, published in Journal of the Australian Welding Institute, vol. 3, no. 11, pp. 7-10 (July 1960).

"Brittle-Fracture Tests of Six-Foot Wide Prestressed Steel Plates" by F. W. Barton and W. J. Hall. A report on work done under SSC Project No. SR-137, published in The Welding Journal, 39:9, Research Supplement, pp. 379s-384s (September 1960).

"A Reversed-Bend Test to Study Ductile to Brittle Transition" by J. H. Ludley and D. C. Drucker. A report on work done under SSC Project No. SR-158, published in The Welding Journal, vol. 39, no. 12, Research Supplement, pp. 543s-546s (December 1960).

"Physical Metallurgy and Mechanical Properties of Materials: Brittle Fracture" by B. L. Averbach. A report on work done under SSC Project SR-136, published in Journal of the Engineering Mechanics Division, Proc. Amer. Society of Civil Engineers, vol. 86, no. EM 6, Part 1, pp. 29-43 (December 1960).

APPENDIX H

STATISTICAL REPORT OF STRUCTURAL FAILURES OF STEEL MERCHANT VESSELS TO MARCH 1961

This appendix is a continuation of the reports of casualties in the _Final Report of a Board of Investigation to Inquire Into the Design and Methods of Construction of Welded Steel Merchant Vessels_, dated July 15, 1946 and available upon request from the Ship Structure Committee, and the four Technical Progress Reports that have been issued since then by the Ship Structure Committee.

In accordance with the practice inaugurated in the Fourth Technical Progress Report, only Group I fractures are reported. A Group I fracture is one that is at least ten feet long and has weakened the main hull structure sufficiently either to sink the ship or place it in a dangerous condition until adequately repaired.

GROUP I CASUALTIES UP TO MARCH 31, 1961

(Continued from *Ship Structure Committee Report of May 1, 1960*)

ABS CODE	TYPE	YARD	DELIV. DATE	CAS. DATE	LOADING	SEA COND.	WIND FORCE	SHIP SPEED	AIR TEMP.	SEA TEMP.	LOCATION OF FRACTURE	ORIGIN OF FRACTURE	REMARKS
336	C-4	Sun	5-45	3-60	Loaded	H.W.					Mn. dk. from fwd. stbd. corner No.5 hatch to riveted stringer flat bar bet. frs. 105/106 for abt. 25'.	Hatch corner	
337	EC-2	Permanente No. 1	10-43	3-60	Ballast	H.W.					Mn. dk. & hatch corner dblr. from stbd. side No.3 hatch to sheer-strk. fwd.of fr. 82 for abt. 12'. Port side from No.3 hatch to sheerstrk. aft fr. 74 for abt. 12'.	Abt. 12" aft & 12" fwd. of hatch corners, at ends of slots in hatch coamings.	
338	C-3	Ingalls	3-43	12-59		WSW Rough	5 WSW	16 1/2 knots	29°- 32°	52°	Mn. dk. port for abt. 13' transv'ly from sounding pipe fitting fwd. of fr. 47 to kingpost dk. connection weld aft fr. 47; dblg. pl. around kingpost fractured. Hatch corner dblr. stbd. fwd. end No.2 hold fractured.		
339	541' Tnkr	Welding SY	9-45	6-60	Deeply laden	H.W. (cargo temp. 140°)			67°	66°	Vicinity transv. shell frs. 46, 47 & 48 (from aft) passing under long'l bhd. bet. No.3 center & stbd. tanks.		Fractured with loud report. Bt.pltg.heavily pitted & previously blt. up by welding.
340	EC-2	Permanente No. 2	4-43	12-59	Auto-mobiles	H.W.			37°	55°	Mn. dk. port fwd. corner No. 3 hatch to sheerstrk. for abt. 18' & from aft corner No.3 hatch, stbd, abt. 18' to sheerstrk.	Hatch corners	Vessel laboring & straining heavily.
341	C-4	Sun	6-45	10-60	General cargo	H.W.	5 NW		52°- 55°	52°- 60°	Mn. dk. port aft corner No. 5 hatch outbd. for abt. 25' ending at rivet hole in stringer flat bar.	Dk. pl. butt weld at side coaming abt. 3'6" fwd. of aft port corner No.5 hatch.	Vessel pitched heavily in unexpected nw'ly swell. Fractured with loud rpt.
342	EC-2	J.A. Jones	5-44	11-60	Iron ore	H.W.					Mn. dk. port aft corner No.4 hatch around edge corner dblg. pl. outbd. hatch to seam of riveted dblr. for abt. 11.5'.	Hatch corner	Vessel consists of two EC2's joined together.
343	T-2	Alabama	8-43	12-60	Ballast	H.W.	12	74/60 RPM			Broke in two off Cape Hatteras. Bow section lost, stern section salvaged.	Bottom. Mostly ductile.	Ballast concentrated amidships.
344	EC-2	Oregon	1-44	12-60	Loaded	H.W.					Mn. dk. port in way house front, aft end No.3 hatch, fr. 83, extending from sheerstrke. abt. 15' inbd.		
345	Brg.	Albina	5-46	1-61	Sulphur	H.W.	To 25 knots				Broke in two & sank 10 mi. east of Palm Beach.		Towline from tug broke. "Mountainous" seas (Ex Cl-Mt-BU1)
346	EC-2	South-eastern	1-45	2-61	Iron ore	H.W.					Stbd. bott. pltg. in way No. 3 d.b. tank transv'ly for abt. 13' bet. frs. 84/85 from pl. D9 thru C7 into B8.		
347	T-2	Kaiser	10-43	1-61	Ballast	NW swell			37°	43°	Port shell pls. J7, H7, H8 & G8 for over 12'	End of long'l L6.	
348	C-2	No. Carolina	2-44	3-61	Loaded	Hvy NW swell	4-6	Abt.86 RPM	51°	62°	Mn. dk. port stringer from crack arrestor slot to gunwale bet. frs.73/74 down sheerstrk.pl.K9 & J9 for abt.12'.	Possibly butt weld failure.	
349	Cargo 465'-10"L.	Nippon Kokan K.K.	1-54	3-61	Loaded	Hvy NNE swell	6	16 knots	39°	38°	Tanktop centerline rider pl. long'ly for abt. 12' bet. frs. 126/132, approx. 3 1/2" inbd. of welded port lapped seam.		

APPENDIX I

SHIP STRUCTURE COMMITTEE

Allocation of Funds from Agency Budgets

	THOUSANDS OF DOLLARS				
		BUDGET YEAR			
	1946--1958 Inclusive	59	60	61	TOTAL
U. S. Coast Guard	$ 1045	$ 100	$ 100	$ 100	$ 1345
U. S. Maritime Administration	580	100	100	100	880
Army Transportation Corps	93	0	0	36**	129
*U. S. Navy BuShips	2387	200	175	200	2962
American Bureau of Shipping	16	2	2	2	22
TOTAL	$ 4121	$ 402	$ 377	$ 438	$ 5338

*Includes Military Sea Transportation Service since 1951.
**These funds were provided for additional special studies under Project SR-153.

APPENDIX J

RECOMMENDED BUDGETS FOR 1962 AND 1963

On the following pages are listed the recommendations for the next two years. The 1961 estimated expenditures are listed for comparison. The recommendations for 1963, which exceed the normal funds available, are included for planning purposes.

Description of "Administration and General" items:

Coordination. This covers operation of the staff and committees of the National Academy of Sciences-National Research Council, as described in more detail in Appendix E.

Materials Testing. Watertown Arsenal Laboratories has assisted the Ship Structure Committee through performance of special testing, either for one of the established research projects or for cases of service failure of more than routine interest.

Materials Purchase. This provides for separate purchase by the Bureau of Ships of steel as required by Ship Structure Committee investigators, which is not provided for in the separate contracts.

Fabrication Travel. This provides traveling expenses where needed for members of advisory committees under the Fabrication Program.

IIW Activity. This provides financial support to individuals associated with the Ship Structure Committee for participation in activities of the International Institute of Welding, of which the Ship Structure Committee is a member.

PROJECT	TITLE	LOCATION	THOUSANDS OF DOLLARS 1961	1962	1963
SR-146	Structural Design Mono.(Index)	SWRI	1	--	--
SR-149	Low-Cycle Fatigue	Ill.	25	30	35
SR-153	Ship Response Statistics	Lessells	62**	25	50
SR-154	Slamming Studies	UCB	20	25	40
SR-155	Low-Velocity Fracture	Ill.	20	--	--
SR-157	Model in Extreme Waves	SIT	20	--	--
SR-158	Macrofracture Fundamentals	Brown	20	35	50
SR-161	Temp. Dist. & Thermal Stress	UCB	18	18	25
- -	Bending Moment Determination	SIT	--	20	20
- -	New Projects	--	--	--	25
	TOTALS FOR DESIGN PROGRAM		186	153	245
SR-125	Survey of Current ABS Steels	NYNSY	30	--	--
SR-136	Metallurgical Structure	MIT	55	63	70
SR-139	Joint SSC-AISI Study	NBS	5*	--	--
SR-147	Mill Rolling Practice	MIT	20	25	30
SR-151	Met. Variables & D-W Test	BMI	20	--	--
SR-162	Optimum Comp.--Experimental	Lehigh	15	25	30
- -	New Projects	--	--	--	25
	TOTALS FOR MATERIALS PROGRAM		145	113	155
SR-150	Residual Stress Determination	BMI	20	20	25
SR-160	Non-graphic Flaw Indicators	NRDL	10	--	--
- -	Shipyard Flaw Evaluation	--	--	20	25
- -	Weld Metal Toughness	--	--	20	20
	TOTALS FOR FABRICATION PROGRAM		30	60	70

*Jointly supported with another group--See Administrative Summary.
**$36,000 of this total was provided by the Army Transportation Corps for special studies.

TITLE	LOCATION	THOUSANDS OF DOLLARS 1961	1962	1963
Coordination	NAS-NRC	67	67	67
Materials Testing	WAL	5	--	--
Materials Purchase	BuShips	--	1	1
Fabrication Travel	USCG	3	3	3
IIW Activity	--	--	5	5
TOTALS FOR ADMINISTRATION & GENERAL		75	76	76

PROGRAM RECAPITULATION	1961	1962	1963
Design	186	153	245
Materials	145	113	155
Fabrication	30	60	70
Administration & General	75	76	76
GRAND TOTALS	436	402	546

The following abbreviations have been used:

Abbreviation	Name in Full
BMI	Battelle Memorial Institute
Brown	Brown University
BuShips	Bureau of Ships
Ill.	University of Illinois, Urbana
Lehigh	Lehigh University
Lessells	Lessells & Associates, Inc.
MIT	Massachusetts Institute of Technology
NAS	National Academy of Sciences
NRC	National Research Council
NBS	National Bureau of Standards
NRDL	Naval Radiological Defense Laboratory
NYNSY	New York Naval Shipyard
SIT	Stevens Institute of Technology
SWRI	Southwest Research Institute
UCB	University of California, Berkeley
USCG	U. S. Coast Guard
WAL	Watertown Arsenal Laboratories